CONTINUOUS HIGH VELOCITY JET EXCAVATION - PHASE I

FINAL REPORT

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13. ABSTRACT

The objective of this program was to assess the feasibility of rapid excavation of hard rock by means of continuous fluid jets produced by pressures in the range of 20,000 to 80,000 pounds per square inch. A total of eight rock types representative of sedimentary, metasedimentary and igneous groups were selected and appropriate quantities of test specimens were procured. Cutting tests were performed using Bendix-owned pumping equipment and Bendix-designed and developed nozzles. Test data was analyzed to determine optimum settings of jet parameters within experimental ranges that result in rapid and efficient excavation of rock. Power requirements and excavation rates were estimated for a theoretical continuous jet excavation system and compared with those of a conventional system.

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SECTION 1

SUMMARY

The objective of this program was to investigate the feasibility of rapid excavation systems for hard rock using high-velocity continuous fluid jets. Both single-cut and kerfing excavation modes were experimentally investigated in order to minimize the specific energy (i.e., energy input per volume excavated) of jet fragmentation. Ranges of variables were nozzle supply pressures from 50,000 to 80,000 psi (34.5 to 55.2 KN/cm^2), feedrates from 50 to 900 inches per minute (2 to 38 cm/sec), standoff distances from 0.5 to 1.5 inches (1.27 to 3.81 cm), and nozzle diameters of 0.008 to 0.0136 inch (0.20 to 0.35 mm). The rock types used in fragmentation tests were Berea Sandstone, Salem Limestone, Tennessee Marble, Westerly Granite, Barre Granite, Charcoal Granite, Sioux Quartzite and Dresser Basalt.

Initial fragmentation tests, employing a 2^4 factorial design, were completed on all rock types to perform screening of the four independent variables. Analyses of variance were completed upon the 2^4 factorial data to determine the two most significant main effects for each rock type, which were then investigated at a third level. Randomization was applied to the sequence of test runs as well as the selection of samples within each rock type. Additional testing was undertaken at higher feedrates than those originally planned, up to a maximum of 38 cm/sec (900 inches per minute) based on predictions from the variance analyses.

Within the experimental range, the minimum specific energies for single cuts were obtained for most rock types at 50,000 psi (34.5 KN/cm^2), at 900 inches per minute (38 cm/sec), using a 0.008 inch (0.20 mm) diameter nozzle. Kerfing tests were conducted for each rock type using the parameters which produced the minimum single-cut specific energy. Minimum specific energies for kerfing runs ranged from 6611 joules/cc, (79,900 ft-lb/in^3) for Sioux Quartzite to 1215 joules/cc (14,685 ft-lb/in^3) for Berea Sandstone.

The kerfing specific energy was found to be too high to justify the use of an excavation system utilizing jet action alone instead of a conventional tunnel excavator. Test data was utilized, however, in the generation of a mechanically assisted fluid jet excavation machine concept having a significantly reduced overall specific energy. The specific energy calculated for the hybrid system does not, however, represent the optimum specific energy for such a system since the jet operating parameters employed in the analysis were those which gave the minimum specific energy for pure jet excavation. These parameters were also observed to give the smallest kerf depths. As kerf depth is increased, the spacing

between kerfs can also be increased, thereby increasing the volume of material removed by mechanical action. Since the jet excavation energy constitutes the majority of the energy input to the rock, the maximum overall efficiency for a hybrid system may be obtained at the operating parameters which produce the deepest kerf, even though the jet excavation portion of the process is not operating at its minimum specific energy.

Further investigation is indicated to determine specific energy for excavation of *in situ* rock structures as well as for optimization of jet operating parameters in combination with mechanical breakage methods. Combination of the more favorable stress condition of *in situ* rock with optimization of the specific energy of a mechanically assisted jet excavator is expected to reduce the overall system specific energies to levels comparable to those demonstrated by conventional excavation systems operating in hard rocks while preserving the major advantages of the jet approach.

SECTION 2

INTRODUCTION

Increasing emphasis in both urban and defense systems planning has focused upon the desirability of locating many utilities and transportation systems underground. Such a location frees valuable land space within city centers and allows greater flexibility in planning for urban development. In many population centers, tunneling is the only viable method of building mass transportation systems due to the high degree of utilization of surface space. Underground location of facilities has a great advantage from the military standpoint due to decreased vulnerability to attack and sabotage. Additionally, underground systems and structures are impervious to weather conditions and may be maintained in a controlled environment which will reduce both construction and maintenance costs. Protection from weather is a basic requirement for planned future high speed ground transportation systems.

Implementation of a large scale relocation of surface facilities underground will require major advances in present tunneling technology, resulting in the evolution of efficient, cost effective, rapid excavation systems. Present tunneling methods are generally too slow, expensive and not versatile enough for use in other than certain specific applications.

The foremost problem of any mining or tunneling system is to break the material out of the solid matrix at the cutting face of the tunnel and reduce it to a size suitable for removal. Presently, there are two basic material removal methods, the cyclic drill-blast method and the continuous cutting machine method.

The drill-blast method, in which the material is removed by the detonation of explosives loaded into small diameter holes drilled in the face, is the method most commonly used, as it can be used in any rock from sedimentary to the hardest igneous. Disadvantages of this method include explosives hazards, generation of dust and fumes and weakening of the rock strata due to concussion, with attendant overbreakage and rock falls. Although the actual specific energy of the blasting process is low, the fact that the process is cyclic, with the various operations of drilling, charging, blasting, clearing of fumes and muck removal occurring sequentially instead of continuously, contributes to the disproportionately high cost and low excavation rate of the overall operation as compared with continuous excavation processes.

The continuous cutting machine method, wherein material removal is effected by means of mechanical excavating machines with cutter bits mounted on endless chains or rotary drill bits, is in the early development stages and is presently limited to medium hard rock applications.

Within these applications, however, the continuous cutting machine method is comparable to the drill-blast method in both cost and speed of tunneling and mining. In addition to the disadvantage of dust generation by the cutters, the rate of material removal by the continuous excavating machine is limited by the thrust which must be developed in order to push the bits against the work face, in many contemporary machines exceeding one million pounds. The machine structure required to generate forces of this magnitude results in high capital cost, low maneuverability and difficulties in performing maintenance. In the harder or more abrasive rock excavation applications rapid cutter wear occasioned by high loading and cutter bearing failures due to contamination by abrasive particles make the continuous excavation machine uneconomical in comparison with the drill-blast method, in spite of the advantages of continuous operation and superior control of tunnel line, grade and size. It appears, therefore, that the success of any efforts toward increasing the speed with which tunnels or mines can be excavated will depend upon the development of new methods of excavating material at a much faster rate with less part wear.

A novel method of material excavation which is presently under investigation is the use of high pressure fluid jets, a process which, in combination with certain areas of present tunneling and excavation technology, has the potential of producing higher excavation rates than present methods, while simultaneously eliminating or reducing many of their major disadvantages.

The basic technique is not new, since jets of water at low pressures were used for eroding terrain in placer maining in the California gold fields as early as 1870. Within the past several years, hydraulic mining of coal using water pressures of 3000 to 5000 psi has been successfully developed and is now being used extensively in the USSR. As materials and equipment improved, practical generation of higher pressures became possible and investigations were begun into the drilling and breaking of harder rocks. To date, only limited data was available on the use of continuous water jets at pressures above 25,000 psi.

When a moving column of fluid is allowed to impinge on a solid body, the surface of the body at the point of jet impingement is subjected initially to a short-duration high-pressure transient resulting from the water hammer effect; this is followed by decay to some steady-state pressure level. The magnitude of the high-pressure transient is a function of the jet velocity and fluid properties and can be twice the nozzle supply pressure; the steady-state pressure may approach the nozzle supply pressure. For example, a water jet produced by a nozzle supplied at a pressure of 50,000 psi could theoretically generate water hammer and steady state surface pressures of 100,000 and 50,000 psi, respectively. Comparison of these values with the average ultimate compression strengths of some rock and earth materials indicates the merit of investigating high-velocity fluid jets as a means of cutting and fracturing.

Advantages of the water jets for excavation of rock as opposed to conventional tunneling methods are decreased tool wear and decreased reaction forces against the work face. In addition, the fluid jet is safer than conventional methods. The jet action does not weaken the surrounding material, as does blasting, and eliminates the sparking and attendant gas explosion dangers experienced with mechanical cutters. The material and water slurry resulting from continuous jet action also minimizes dust hazards to workers and opens possibilities for material removal by pipeline transport. Establishing the feasibility of fluid jet rock excavation is expected to provide a base for development of efficient and economical systems for tunneling and excavation.

SECTION 3

PROGRAM BACKGROUND

As a part of the Advanced Research Projects Agency (ARPA) Military Geophysics program, the Bendix Research Laboratories has conducted an experimental study to determine the feasibility of a continuous jet excavation system for hard rock using jet supply pressures of 20,000 to 80,000 psi. Efforts were performed under Contract No. H0210034, which was administered by the U.S. Bureau of Mines. Project officers at the Twin Cities Mining Research Center were initially Mr. John Chester and, subsequently, Dr. Peter Lohn.

The primary objective of the program was to generate data in a statistically designed experiment to determine the most optimum operating conditions for a continuous jet excavation system. Existing company-owned high pressure pumping equipment and nozzles were utilized to permit in-depth experimentation in a range of pressures and nozzle diameters beyond that of previous investigations utilizing continuous jets. Included in the present effort were purchase of samples, preparation of a test plan, fracture tests, data compilation, analysis and presentation of results for eight different rock types. Both single cut and kerfing excavation modes were investigated in order to minimize the specific energy (i.e., energy input per volume excavated). Process parameters employed were pressures from 50,000 to 80,000 psi, feedrates from 50 to 900 inches per minute, standoff distances from 0.5 to 1.5 inches, and nozzle diameters of 0.009 to 0.0136 inch. The rock specimens used in fragmentation tests were Berea Sandstone, Salem Limestone, Tennessee Marble, Westerly Granite, Barre Granite, Charcoal Granite, Sioux Quartzite and Dresser Basalt. Compression strengths for the rock types ranged from 8,600 to 54,000 psi.

Early in the program, a specific test plan, described in Sections 5 and 6, was generated, purchase orders were placed for samples of the rock types specified, and fragmentation testing scheduled to commence following receipt of the rock samples. Delays were encountered in both the procurement of rock test specimens and in maintenance of the BRL high pressure intensifier. Due to late deliveries of samples from several vendors, the initiation of fragmentation tests were delayed. In addition, during periodic maintenance of the high pressure pumping system to be used for the fracturing tests, severe scoring of the high pressure pistons and cylinders was discovered. The intensifier was removed from the high pressure facility and shipped to the manufacturer for determination of both the severity of the damage and the length of time required to complete repairs.

Since the repair and return of the intensifier unit was essential to the continuation of the testing, the program was delayed by an amount of time equal to that required for completion of repairs. In the interim,

other program tasks were carried as far as possible in order to minimize schedule slippage due to the intensifier failure. After repairs were completed, the high pressure intensifier was returned to Bendix. Rock samples were moved into the test area and initial runs were completed on several rock samples for use in evaluating various methods of determining the material volume removed by the jet.

Fragmentation tests were begun in early January 1972. Samples were fixtured to a traverse mechanism under a stationary fluid jet, with supply pressure, traverse speed and standoff distance as recorded variables. The equipment and test setup is described in Section 4.

Initial fragmentation tests employing a 2^4 factorial design were completed on all rock types to perform screening of the four independent variables. Analyses of variance were completed upon the 2^4 factorial data to determine the most significant main effects, for each rock type, which were then investigated at a third level. Randomization was applied to the sequence of test runs as well as the selection of samples within each rock type. Additional testing was undertaken at higher feedrates than those originally planned, up to a maximum of 900 inches per minute, based on predictions from the variance analyses. Although the variance analyses indicated that further reductions in specific energy value could be obtained at lower pressures and nozzle diameters than those used in the test program, full exploration of this range was beyond the scope of the current contract.

Within experimental ranges, the minimum specific energies for single cuts were obtained for most rock types at the lowest supply pressure, highest feedrate, and smallest nozzle diameter, that is 50,000 psi, 900 inches per minute, and 0.008 inches respectively. Following determination of the minimum specific energy for single cuts, spacing between successive cuts was decreased until kerfing, or excavation of the material between the cuts, was observed, which indicates the condition of minimum overall specific energy. Kerfing tests were conducted for each rock type using the parameters which produced the minimum single-cut specific energy. Specific energies for kerfing runs ranged from 6611 joules/cc (79,900 ft-lb/in^3) for Sioux Quartzite to 1215 joules/cc (14,685 ft-lb/in^3) for Berea Sandstone.

Program test data was utilized in the generation of a mechanically assisted fluid jet excavation machine concept, described in Section 8, for use in an economic comparison with conventional excavation systems. Conclusions and recommendations for further development are presented in Section 9.

SECTION 4

TEST SETUP

Equipment employed in conducting fragmentation testing included a high pressure intensifier with its hydraulic power supply and control system, and a calibrated traversing mechanism for moving the samples under the stationary jet nozzle. All equipment is owned by Bendix Research Laboratories and is employed in investigations of the feasibility of using high pressure jets for cutting and machining of industrial materials.

The high pressure intensifier, shown in Figure 4-1 and schematically in Figure 4-2 is a commercially available double-acting device capable of an output of 1.4 GPM at 80,000 psi, driven by a conventional hydraulic power supply. The high pressure fluid, generally water or water with soluble oil, is plumbed through the outlet check valves into a surge vessel mounted below the intensifier unit. The surge vessel acts as an accumulator, using the compressibility of the water at high pressure to minimize output pressure fluctuations during intensifier piston reversals. The cycling reversals are controlled by a directional control valve, actuated by two limit switches which signal the end of each stroke.

The high pressure fluid is plumbed from the surge vessel to the nozzle assembly, shown projecting from the wall in Figure 4-3, which is a view of the test cell in which the fragmentation tests were run. The nozzles used in all testing were of proprietary Bendix design. The traversing table is capable of moving samples below the nozzle assembly through a 10 inch stroke at feedrates of up to 950 ipm. Feedrates were controlled by means of a calibrated flow control valve in series with the traverse table drive cylinder. The remaining system controls, including the system output pressure gauge, are mounted in a control console shown directly behind the traversing table. Figure 4-4 (a) and (b) are pictures of a cutting test at 50,000 psi conducted upon a sample of Barre Granite.

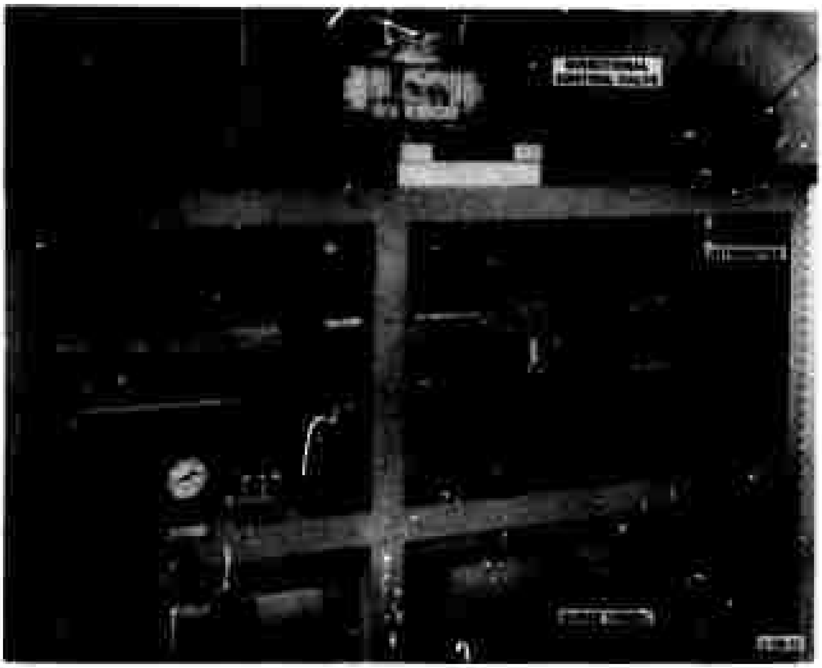

Figure 4-1 - High Pressure Intensifier Pumping System

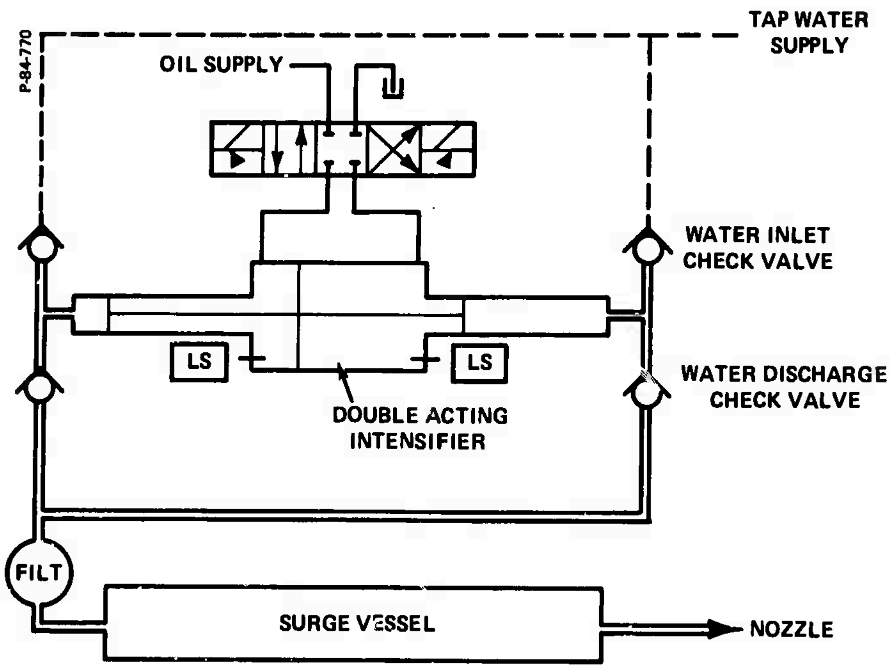

Figure 4-2 - High Pressure Intensifier System Schematic

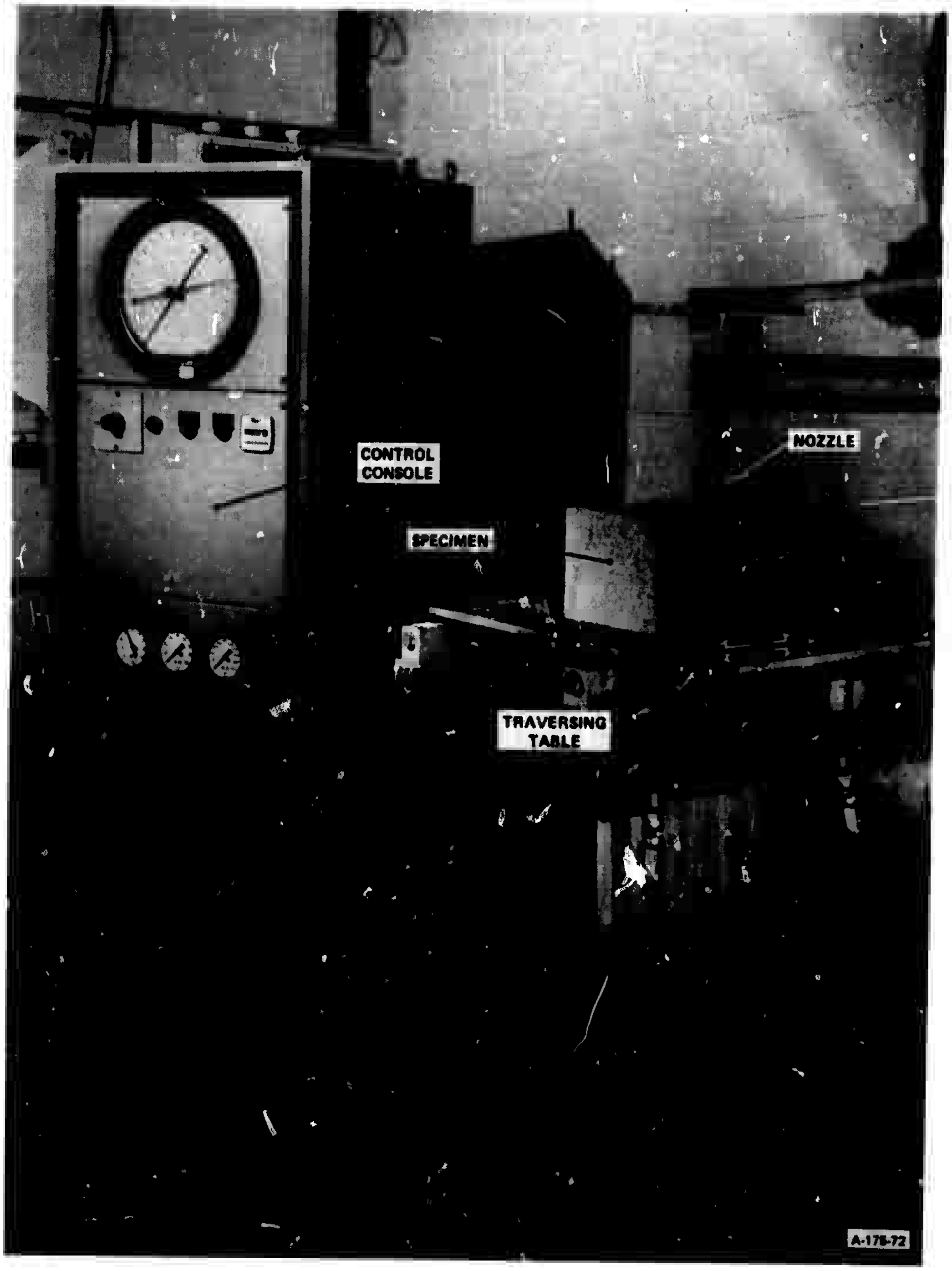

Figure 4-3 - Test Set Up

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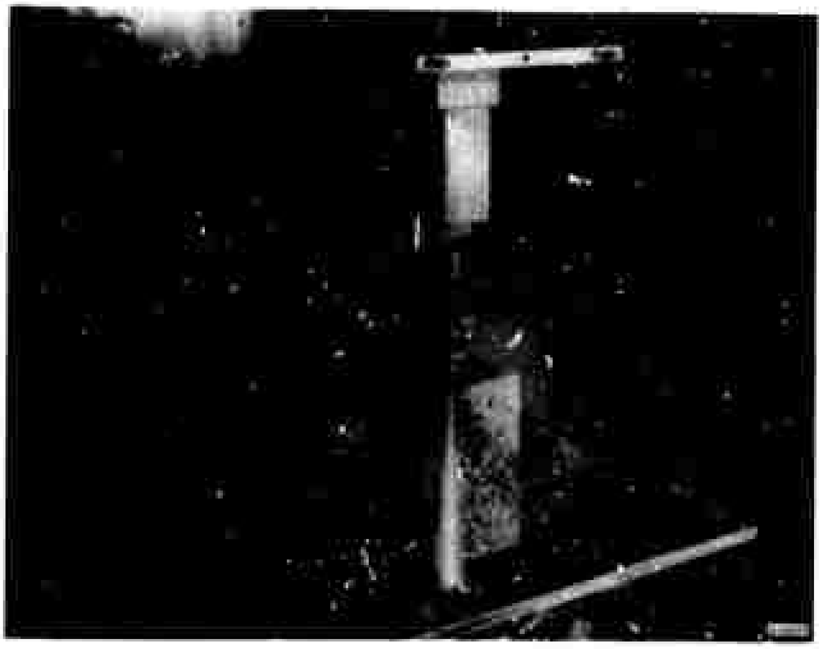


(a) Starting Cut

(b) Partially Complete Cut

Figure 4-4 - Cutting Test on Barre Granite

SECTION 5

PROGRAM EXPERIMENTAL PLAN

Four major independent variables associated with the fluid jet process were investigated, each at three levels. The two levels of the variable used in 2^4 factorial design experiments for significance determinations are denoted by lower case letters, with upper case letters used to denote the levels used for 3^2 and 3^4 factorial design experiments.

The following independent variables were investigated:

Pressure (P) (psi)	$P_1 = 50{,}000 = P_o$
	$P_2 = 65{,}000$
	$P_3 = 80{,}000 = P_1$

Pressure was recorded directly from the system supply pressure gauge.

Feed Rate (F) (inches/per minute)	$F_1 = 50 = f_o$
	$F_2 = 100$
	$F_3 = 150 = f_1$

Feed rate was set using a calibrated flow control valve to drive the hydraulic cylinder which powers the specimen traversing table. Additional tests were completed at higher feedrates up to 900 ipm.

Standoff (S) (inches)	$S_1 = 0.5 = s_o$
	$S_2 = 1.0$
	$S_3 = 1.5 = s_1$

Standoff distance was determined by leveling the sample and mounting it at the desired distance relative to the jet nozzle.

Nozzle Diameter (N) (inches)	$N_1 = 0.008 = n_o$
	$N_2 = 0.012$
	$N_3 = 0.0136 = n_1$

The 0.0136-inch diameter nozzle was sized to utilize maximum flow capacity of the Bendix high-pressure pumping system at 80,000 psi.

In order to minimize the effects of extraneous or unknown variables, the order of test runs as well as the order of rock type for each run was randomized. Each test combination was accorded a combination number, which specified a particular set of test conditions. The test number, indicating the order of completion of each test combination, was determined by selection of combination numbers from a random number table, with the exception of the various levels of nozzle diameter, which were run sequentially due to the greater difficulty involved in changing nozzle size as opposed to changing other operating parameters.

The following eight rock types were used in the experimental effort. Sample size was approximately 8 x 8 x 6 inches in most cases.

- Charcoal Granite (Cold Springs, Minnesota)
- Westerly Granite (Westerly, Rhode Island)
- Barre Granite (Barre, Vermont)
- Dresser Basalt (Dresser, Wisconsin)
- Sioux Quartzite (Jasper, Iowa)
- Berea Sandstone (Amhurst, Ohio)
- Tennessee Marble (Knoxville, Tennessee)
- Salem Limestone (Bedford, Indiana)

Contacts were made with operators of quarries recommended by the Contracting Agent as sources of the rock types listed above, and purchase orders placed for samples in 20-piece lots for all rocks except Westerly Granite, for which only five samples were ordered due to high cost, and Dresser Basalt, which was acquired directly from the Bureau of Mines. Tables of properties for each rock type have been obtained from either the Bureau of Mines or the quarry operators. Since no measurement of rock properties was performed under this test program, rock properties are presented in Appendix A for reference only. The effects of rock property differences between specific samples within each rock type was minimized by randomization of the selection of samples for use. The samples were numbered during uncrating and randomly selected for each test run.

The dependent variable of the experiment was specific energy, the amount of energy required to remove a unit volume of rock. Specific energy was determined for both single cuts and for kerfing, wherein interaction between successive cuts results in the excavation of the material between.

Specific energy was calculated from system operating parameters, sample size and material volume removed, based on the calculated actual power level at the nozzle rather than hydraulic system input power, and therefore is not affected by the inefficiencies of the particular hydraulic system and intensifier used.

Derivation of the specific energy equation is as follows:

$$\text{Specific Energy} = \frac{\text{Power} \times \text{Time}}{\text{Volume of Material Removed}} \tag{1}$$

The intensifier power delivered to the nozzle is given as

$$\text{Power} = 5\ (Q \times \Delta P) \tag{2}$$

Where power is expressed in ft-lb/min

Q = flow, in^3/sec

ΔP = nozzle pressure drop, psi

Since the system flow is governed by the nozzle area

$$Q = C_d\ A \sqrt{\frac{2g\ (\Delta P)}{\rho}} \tag{3}$$

where

Q = flow, in^3/sec

g = gravitational constant = 386 in/sec^2

ρ = fluid density = 0.0361 lb/in^3 for water (assumed incompressible)

ΔP = nozzle pressure drop, psi

C_d = assumed discharge coefficient = 0.75

A = nozzle orifice area, in^2

Since the total pressure head of the high-pressure fluid is converted to velocity head during its passage through the nozzle, the pressure drop is given as

$$\Delta P = (P - P_{ambient}) = P \qquad (4)$$

where

P = nozzle supply pressure, psig

$P_{ambient}$ = 0 psig

Also,

$$A = \frac{\pi}{4} (N)^2 \qquad (5)$$

where

N = nozzle diameter, inches

By combining equations (3), (4), and (5) and substituting into (2)

$$\text{Power} = 5\ C_d \left(\frac{\pi}{4} N^2\right) \left(\frac{2g\ P}{\rho}\right)^{1/2} (P)$$

Substituting numerical values gives

$$\text{Power} = 430.7\ N^2\ P^{1.5} \qquad (6)$$

The time during which power is delivered is determined as follows:

$$\text{Time} = \frac{L}{F} \tag{7}$$

where

L = length of cut, inches

F = feedrate, ipm

By substituting equations (6) and (7) into equation (1)

$$SE = 430.7 \frac{N^2 \; P^{1.5} \; L}{F \; V}$$

where

SE = specific energy, ft-lb/in^3

N = nozzle diameter, inches

P = nozzle supply pressure, psig

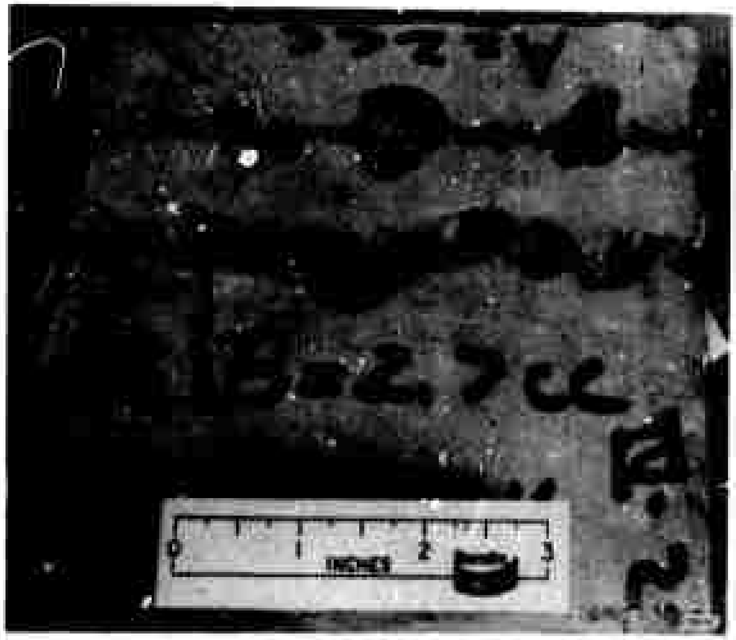
L = length of cut, inches

F = feedrate, ipm

V = volume of material removed, in^3

The volume removed was determined by measuring the volume of material required to fill in the kerf. For the irregular kerf depths and widths obtained in the cutting tests, especially on rocks prone to spalling, measurement of the kerf dimensions and calculation of the volume would be grossly inaccurate as well as extremely time consuming. A variety of materials were used in attempts to fill sample kerfs cut in limestone but were rejected either because of handling difficulties or, in the case of liquids, incomplete kerf filling due to excess surface tension or absorption of the liquid by the rock. The material finally used for the volume measurements was 120 grit emery (aluminum oxide) powder, which has a maximum dimension of approximately 0.004 inch, allowing it to penetrate to the bottom of deep narrow kerfs, but still having sufficient size to permit the material to be poured without caking.

The kerf filling sequence is illustrated in Figure 5-1 for a sample of Dresser Basalt. The ends of the kerf were blocked with tape or putty



(a) Ends of Kerf Prepared for Measurement

(b) Filling Kerf With Powdered Emery

Figure 5-1 - Kerf Measurement Technique

(a) depending upon the regularity of the kerf at the end of the rock. The emery material was poured from a graduated cylinder (b) into the kerf in order to fill the kerf level with the top surface of the rock. For deeper kerfs, the rock was agitated to insure settling of the emery material to the bottom of the kerf. Kerf volume was then equal to the difference between the volume of material in the graduated cylinder before and after filling the kerf. In some cases interaction of the jet with material at the sample edge which had been weakened during sawing or handling resulted in splitting off of a large chunk of material, as shown in Figure 5-2 for a Dresser Basalt sample. In these cases, the kerf was blocked with putty at the ends of the undamaged portion of the sample. Kerf volume and length measurements were taken for the central portion only, eliminating the possibility of the data being influenced or biased by sample stresses induced by the sawing or handling operations.

Figure 5-2 - Effect of Weakened Edge in Dresser Basalt

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SECTION 6

TEST SEQUENCE

Fragmentation tests and analysis were conducted in the following sequence:

- Testing was completed to perform 2^4 factorial experiments for all eight rock types, using the high and low levels of the variables listed previously. Randomization was applied to both the selection of the rock samples and the sequence of the 128 test runs.
- Test data from the 2^4 factorial experiments was processed using Yates algorithm and analysis of variance performed for each rock type to determine the relative significance of main effects and interactions.
- The 2^4 factorial experiments were expanded into 3^4 factorial experiments for both Jasper quartzite, which is the hardest rock specified for the test program, and Barre Granite, which is a relatively common granite for which a variety of information exists.
- Testing was continued to perform, in randomized order, the runs required to complete 3^2 factorial design experiments for the remaining rock types, using the two most significant factors as determined by previous analysis of variance. The remaining two factors were set at the values for which minimum specific energy was obtained.
- Additional test runs were completed for all rock types at higher feedrates up to 900 ipm in order to reduce the single cut specific energy based upon the relatively large significances of the negative feedrate effect as determined from the analyses of variance.
- Kerfing tests were conducted using the minimum specific energy point obtained in the previous testing. Parallel runs across the target face were completed, with spacing between the cuts successively decreased until kerfing occurred between cuts. The kerfing tests were replicated on two additional samples of the same rock type selected at random to minimize the effects of variations in samples within each rock type.

The following number of test runs were completed for each portion of the testing sequence.

2^4 factorial : 2^4 runs x 8 rocks x 2 replications = 256

3^4 factorial: $(3^4 - 2^4)$ runs x 2 rocks x 2 replications = 260

3^2 factorial: $(3^2 - 2^2)$ runs x 6 rocks x 2 replications = 60

Additional:

(2 x 2 x 3) runs x 2 rocks x 2 replications = 48

2^2 runs x 6 rocks x 2 replications = 48

18 extra runs, 2 rocks = 18

Kerfing:

2 runs x 8 rocks x 3 replications = 48

Total number of runs = 738

SECTION 7

DATA AND ANALYSIS

Due to the large amount of data collected for the 738 test runs completed, extensive use was made of the time share computer for data manipulation, calculation of specific energies for each test run and completion of analyses of variance. Computer programs utilized in the test program are listed in Appendix B. Data files are presented so that input data can be retrieved for any run conducted under the test program, if further data analysis is required in future efforts. As mentioned previously, the present effort is devoted specifically to determining for each rock type, the minimum specific energy associated with the jet excavation process within the experimental ranges rather than determination of correlations between specific energy and rock properties. For this reason, as well as the fact that the number of replications is statistically small, regression analyses were not performed on the rock test data. Analysis of the test data will be presented in detail for Barre Granite, which is illustrative of data trends present in most of the rock samples investigated. Due to the total volume of data gathered, however, other rock types will be discussed only with regard to deviations from the established trends. Summaries of process parameters, test conditions, specific energies and analyses of variance are presented for all rock types in Appendices C through J.

As described previously, 2^4 factorial experiments were completed for all rock types for use as screening experiments to determine the relative significances of the jet process independent variables. The results of analyses of variance conducted on the 2^4 factorial data are presented in Table 7-1, with process parameter main effects listed for each rock type in decreasing order of significance. A positive effect, that is, one where the slope of the curve of specific energy versus an independent variable is positive, is denoted by a plus sign before the letter ascribed to the independent variable; a negative effect by a minus. Letters indicating the independent variables are P for pressure, F for feedrate, S for standoff distance and N for nozzle diameter.

The trend for all rock types was for negative feedrate (F) effect, that is, decreasing specific energy with increasing feedrate and a positive nozzle (N) effect. Feedrate was one of the two most significant effects for seven of the eight rock types. The pressure effect was positive for seven rock types, including the three rocks, Barre Granite, Charcoal Granite and Sioux Quartzite, for which it was one of the most significant effects. The standoff effect was positive for the majority of rock types, but was of relatively minor significance compared with the other main effects. Actual significance tests and effect values are presented for each rock type, along with the 2^4 factorial experiment data, in the Appendices.

Table 7-1 - Relative Significances of Main Effects for 2^4 Factorial Fragmentation Test Data

Rock No.	Rock Type	σ comp. (psi)	MAIN EFFECTS (Decreasing Significance →)			
6	Berea Sandstone	8600	-F	+N	-P	+S
8	Salem Limestone	9500	-F	+N	+P	+S
7	Tennessee Marble	16900	+N	-F	+P	+S
2	Westerly Granite	---	+N	-F	+S	+P
3	Barre Granite	23900	-F	+P	+S	+N
1	Charcoal Granite	35100	+P	+N	-F	-S
5	Sioux Quartzite	54000	+P	+N	-F	-S
4	Dresser Basalt	50000	-F	+N	+S	+P

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The 2^4 factorial experimental design was expanded to a 3^4 design for both Barre Granite and Sioux Quartzite, as specified in the test sequence, and into a 3^2 factorial design for the remaining rock types, investigating the two most significant main effects as determined by the previous analyses of variance, in order to provide a better indication of the shape of the specific energy response curves.

Previous research by W. C. McLain et. al.,[1] had indicated that above a certain supply pressure, 12000 psi for Indiana Limestone, and lower for Berea Sandstone, the specific energies became equal for jet impingement both parallel and perpendicular to the specimen bedding planes. Based upon this information, the sample bedding plate orientation was ignored in the current test program, since anticipated supply pressure levels were well above 12000 psi. Berea Sandstone and Salem Limestone samples were ordered with half cut perpendicular and half parallel to the bedding planes, and orientations were distributed among the test sequence by the randomization of the order of sample usage. In order to confirm the validity of this approach, a series of cuts were completed for combination #192 on Indiana Limestone, with two replications each for three faces of the sample to insure impingement both parallel and perpendicular to the bedding plane. The average specific energy for the six tests was 19396 joules/cc and sample variance was 1146 joules/cc. Because of the small differences in the specific energy values obtained in this experiment for three orthogonal rock faces, it appears reasonable to conclude that the orientation of

the jet with respect to the rock bedding plane has no effect upon the specific energy values at the pressure levels used in the present test program.

Of particular interest is the extremely high specific energy values associated with the tests conducted in the 2^4, and 3^4 and 3^2 factorial experiments. The minimum specific energy obtained with this series was 5571 joules/cc (67,348 ft-lb/in^3) for Berea Sandstone. A typical cut is shown in Figure 7-1. The maximum value, however, was 386,191 joules/cc (4,667,923 ft-lb/in^3) for Charcoal Granite, shown in Figure 7-2 Additional testing at different operating parameters was indicated in order to bring the specific energy values down to a point where they could be reasonably competitive with conventional processes. Since nozzle diameter and feedrate had the greatest significances, investigation was begun upon methods of lowering the specific energy by variation of these parameters. The smallest nozzle size presently used and stocked by Bendix is a 0.005 inch diameter, use of which would provide a 60 percent area reduction, and a comparable specific energy decrease, providing the volume excavated remained constant with the smaller nozzle. Previous experience in cutting tests (but not data analysis) conducted for the Bureau of Mines indicated, however, that a lower volume removed could be expected when using the smaller nozzle, so consideration of use of a smaller nozzle for the additional test runs was terminated. By increasing the feedrate up to the practical limit of the sample traversing table, 900 ipm, an 85 percent reduction in energy input to the rock could be realized. A much smaller percentage decrease in excavated volume was expected, since jet efficiency increases at higher feedrates, due to reduced interference between the penetrating jet and the spent jet rebounding from the bottom of the kerf. Additional tests were run at increased feedrates, resulting in a decrease in single cut specific energy to the values presented in Table 7-2.

Analyses of variance were performed upon data from the additional test runs. All rock types exhibited main factor effects having the same sense, but much lower magnitudes, than the effects determined from the 2^4 factorial analyses of variance, indicating that increasing feedrates past 900 ipm will have a decreasing negative effect upon the specific energy. This fact is evident from graphs of specific energy versus feedrate, presented in Figure 7-3 for Barre Granite, with pressure effect illustrated, and Figure 7-4 for Sioux Quartzite, with both pressure and nozzle effects shown. Since feedrates higher than those shown would be of limited utility for a continuous mining machine, it appears that the data presented constitutes a practical minimum single cut specific energy for fluid jet excavation in the experimental range.

Additional testing was completed upon Salem Limestone at pressures as low as 5000 psi in order to determine how well the specific energy data for that rock type matched that presented by McLain[1]. This data presented in Figure 7-5 closely matches at the lower pressures, with the

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Figure 7-1 - Single Cut Run on Berea Sandstone

Figure 7-2 - Maximum Single Cut Specific Energy Run

Table 7-2 - Average Minimum Specific Energies for Each Rock Type

Rock No.	Rock Type	σ comp. (psi)	Minimum Specific Energy				Kerf Spacing	
			Single Cut		Kerfing Cut			
			(joules/cc)	(ft-lb/in^3)	(joules/cc)	(ft-lb/in^3)	cm.	in.
6	Berea Sandstone	8600	2976	35,977	1215	14,686	0.236	0.093
8	Salem Limestone	9500	6036	72,961	2484	30,028	0.236	0.093
7	Tennessee Marble	16900	5130	62,003	3427	41,417	0.317	0.125
2	Westerly Granite	---	6895	83,343	4289	51,843	0.254	0.100
3	Barre Granite	23900	6985	84,425	3857	46,623	0.236	0.093
1	Charcoal Granite	35100	4249	51,355	3963	47,901	0.317	0.125
5	Sioux Quartzite	54000	10834	130,955	6611	79,708	0.317	0.125
4	Dresser Basalt	50000	9579	115,788	3868	46,748	0.317	0.125

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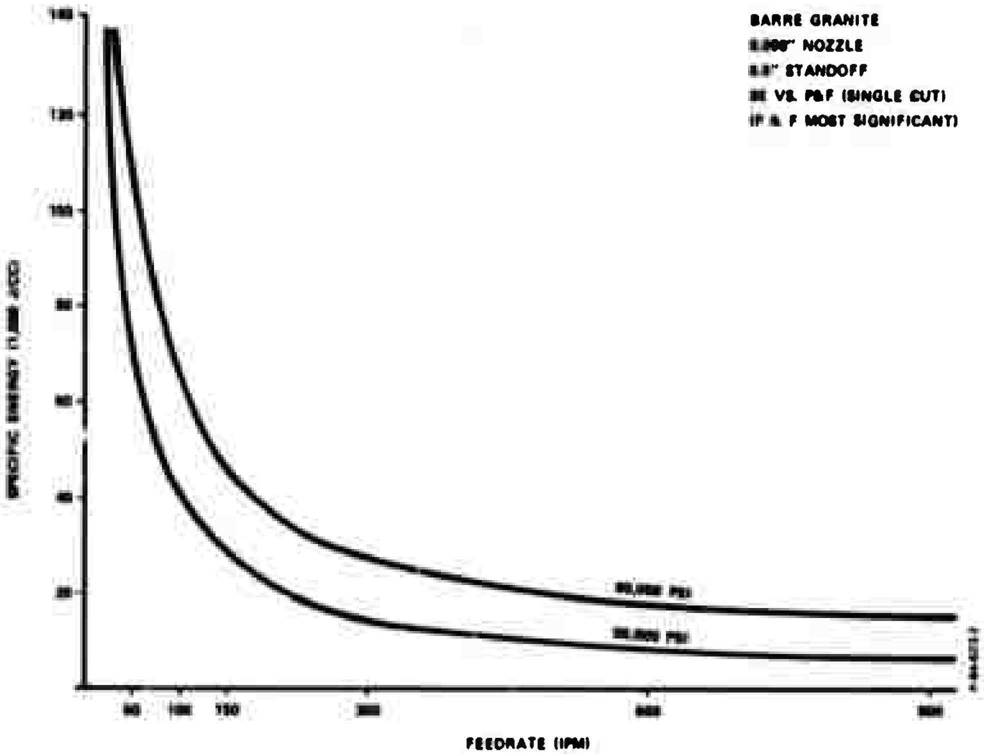

Figure 7-3 - Specific Energy as a Function of Feedrate for Barre Granite

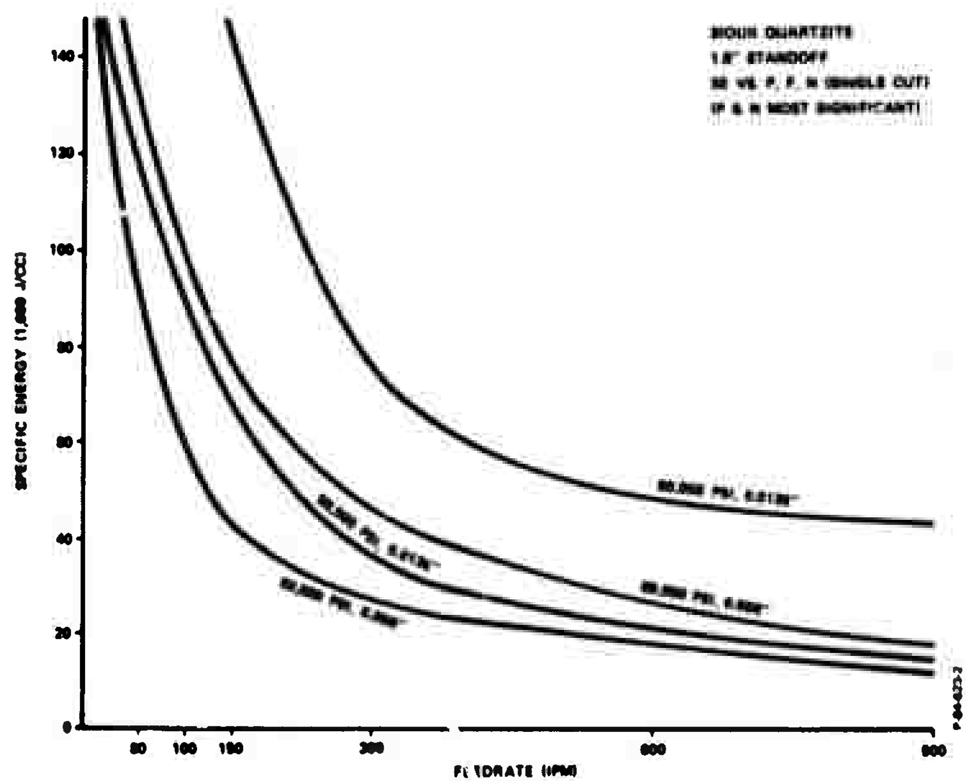

Figure 7-4 - Specific Energy as a Function of Feedrate for Sioux Quartzite

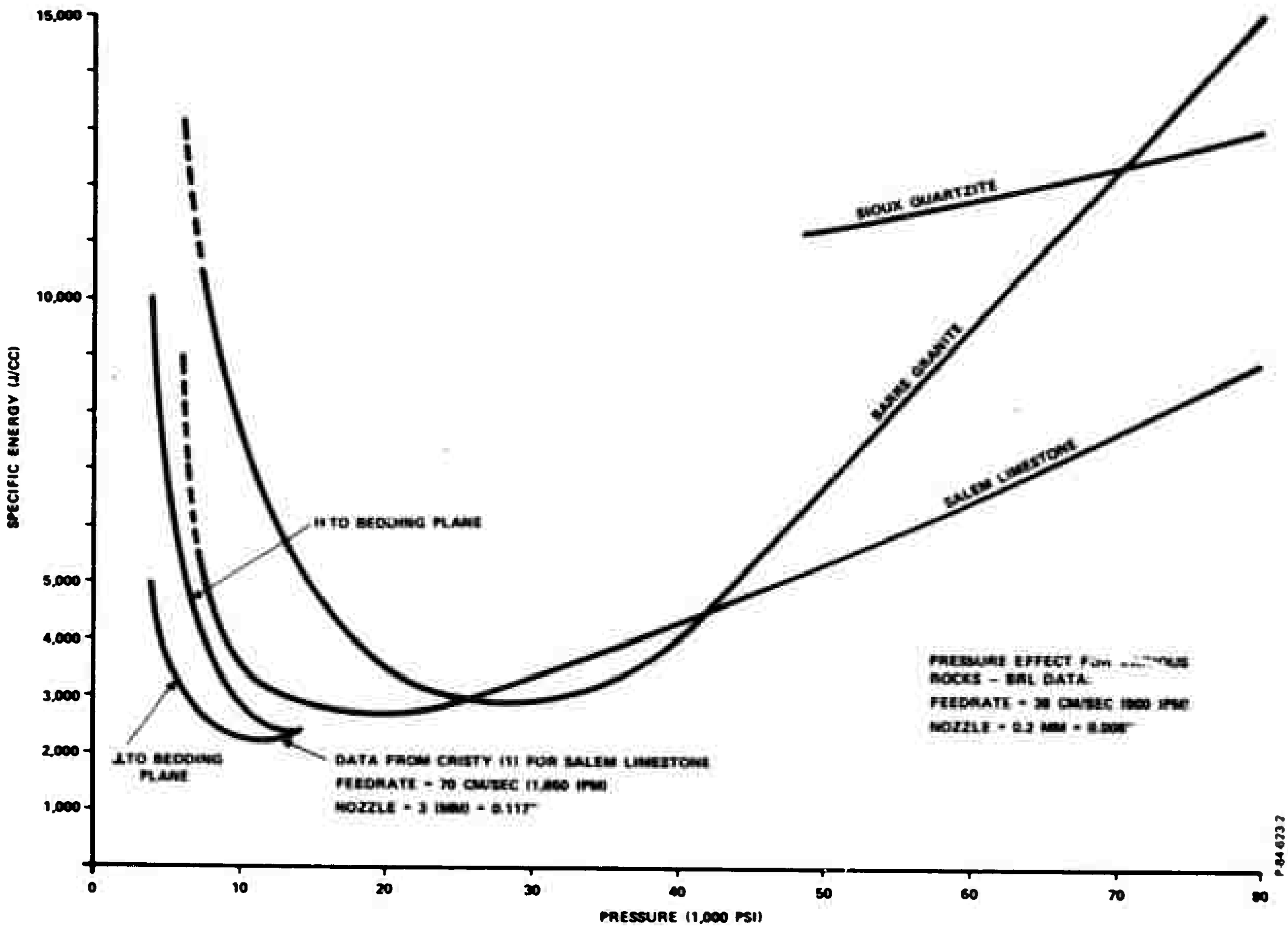

Figure 7-5 - Specific Energy as a Function of Pressure for Sioux Quartzite, Barre Granite and Salem Limestone

decreasing feedrate effect evident in the fact that little additional decrease in specific energy is obtained by increasing feedrate from 900 ipm to 1650 ipm.

Data is also presented in Figure 7-5 for Barre Granite, which the explored at pressures as low as 10,000 psi, and for Sioux Quartzite. The curve for Barre Granite indicates that the minimum specific energy point for this rock occurs at approximately 30,000 psi. The pressure effect curve for Sioux Quartzite is positive, as are the curves for other rock types, indicating that the absolute minimum specific energy point occurs below 50,000 psi for most rock types. Since the pressure effect was not among the two most significant main effects for the majority of rocks, further investigation of specific energies at lower pressures was not pursued.

The minimum specific energy values, within the experimental ranges, determined as described above, were obtained at the following process parameters.

Pressure:	34.5 KN/cm^2 (50,000 psi)
Nozzle Dia:	0.2 mm (0.008 inch)
Feedrate:	19 cm/sec (450 ipm) for Dresser Basalt 38 cm/sec (900 ipm) for all others.
Standoff:	3.81 cm (1.5 inch) for Charcoal Granite and Sioux Quartzite, 1.27 cm (0.5 inch) for all others.

Following determination of the minimum specific energy for single cuts as above, tests were completed to determine the spacing between successive cuts for which kerfing, or excavation of the material between the cuts, was observed, approximating the condition of minimum overall specific energy for fluid excavation at the test conditions employed. The kerfing tests were conducted for each rock type using the parameters listed above which produced the minimum single-cut specific energy. Specific energies for kerfing runs are presented in Table 7-2, along with the maximum cut spacing at which kerfing between cuts would occur. Figures 7-6 and 7-7 show the results of kerfing cuts conducted on Salem Limestone and Barre Granite, respectively.

Figure 7-6 - Kerfing Effect on Salem Limestone

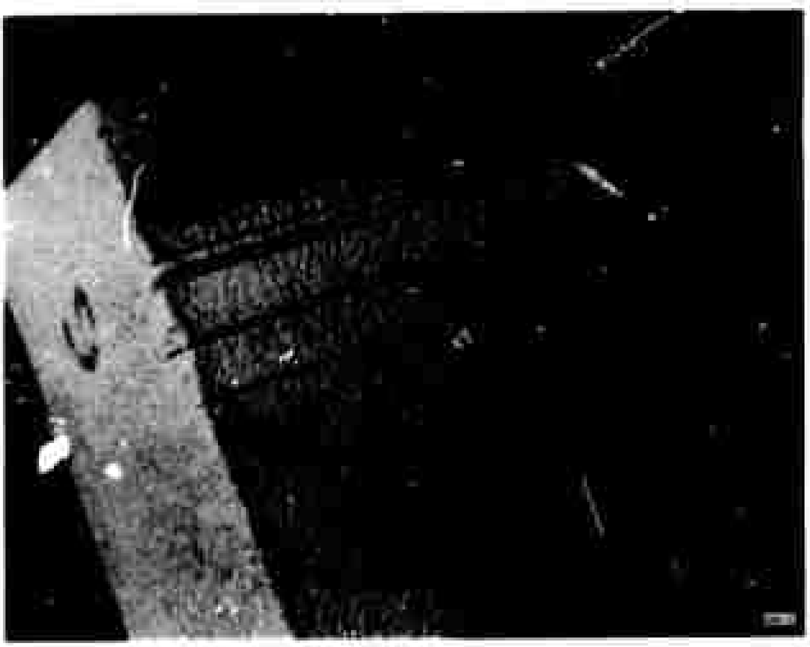

Figure 7-7 - Kerfing Effect on Barre Granite

SECTION 8

FLUID JET EXCAVATION SYSTEMS

Economic comparison between fluid jet excavation systems and conventional continuous excavation systems is hampered by the fact that very little actual tunneling has been completed in hard rock structures for which the use of a fluid jet system is proposed. Bruce and Morrell[2] list a total of only twelve tunnels in the United States which have been machine bored since 1955 in rocks of over 20,000 psi compressive strength. In half of these applications, the use of the continuous excavation machine was discontinued in favor of conventional tunneling techniques. The present limit of economic boreability for most rocks using conventional systems appears to be 30,000 psi compressive strength.

Sufficient data exists from the above source, however, to determine the economics of conventional tunneling systems in two specific hard rock applications, one in argillites having 35000 to 45000 psi compressive strength, in the Dorchester Water Tunnel, Boston, Massachusetts, the second in a section of quartzite of 49000 psi compressive strength in the Magma Copper Mine, Superior, Arizona. Both tunnels were bored by 12.5-foot diameter Lawrence HRT-12 excavators of 600 horsepower capacity with 1,500,000 pounds of thrust upon the tungsten carbide cutters. System cost was approximately $600,000 in both cases. Comparative performance for both systems are presented in Table 8-1. The

Table 8-1 - Comparison of Performance of Various Excavation Systems

Excavation System	Power Required (hp)	Excavation Rate (yd^3/hr)	Specific Energy ($ft\text{-}lb/in^3$)	Specific Energy (joules/cc)
Argillites (σ = 35000 psi)				
Lawrence HRT-12	600	22.7	1122	93
Fluid Jet	51100	22.7	47901	3963
Jet/Mechanical	16450	22.7	15409	1275
Quartzite (σ = 50000 psi)				
Lawrence HRT-12	600	4.5	5608	464
Fluid Jet	17100	4.5	79708	6611
Jet/Mechanical	4096	4.5	19145	1584

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jet specific energy for kerfing cuts in Sioux quartzite and Charcoal granite were used to predict jet excavator performance in quartzite and argillite, respectively.

As is evident from the comparative performance data, the pure fluid jet excavation system, utilizing fluid induced kerfing alone, is at an extreme disadvantage due to its higher specific energy, which is approximately 14 times that for the Lawrence miner operating in quartzite, and 43 times the value for operation in argillites. Assuming an overall machine efficiency of 50 percent, a pure fluid jet excavator would require an installed horsepower of 17,100 to equal the performance of the Lawrence miner in quartzite. Since generation and application of such power levels is impractical in a mobile underground excavation system, it is evident that the use of a hybrid system, combining jet kerf cutting ability with some more efficient method of rock removal, will be required to decrease the overall system specific energy.

The use of a hybrid system utilizing high pressure fluid jets for kerf cutting, with removal of material between kerfs by mechanical means, appears to offer advantages over both pure fluid jet and conventional excavation systems. Such a system, shown schematically in Figure 8-1, will eliminate the high cutter loading and thrust requirements of present conventional excavation systems, as well as minimizing the effect of the high specific energy associated with the pure fluid jet cutting process. Present excavation systems for hard rock use rely on inducing rock spallation due to localized loading of the rock in excess of its compressive strength. Due to the excellent compressive properties of rock *in situ* extremely high cutter loadings are required, with attendant high wear. Also, the spalled material from the rock face tends to contaminate the cutter bearings, resulting in reduced life for these parts. The jet process on the other hand, can remove small kerfs, albeit at high specific energy values, without the need for excessive loading because the machine does not contact the work face. A mechanical device can be inserted into a kerf, as shown, breaking off one rib into the adjacent kerf, and the other rib into the kerf removed by previous passes of the jets and wheel. Although an additional jet kerf must be cut for the first pass in order to insure the removal of two ribs, the extra energy required for the initiating kerf cut will be small when averaged over many succeeding passes, so that, in effect, only one jet excavated kerf will be required for each rib removed. The ribs left in the rock after scoring by the jets are unrestrained, as shown in Figure 8-1, Section A. When loaded by the wheel, the ribs will react similar to end loaded cantilever beams, with a tensile bending load resulting in fracture at the base of the rib, shown in Section B, where the bending moment is largest. Reduced loading and specific energy are required to effect fracture of the rib due to the low tensile strengths of most rocks. In tests to date, Summers and Henry[3] have reported specific energies as low as 0.05 joules/cc for mechanical removal of ribs left between water jet kerfs cut in Berea

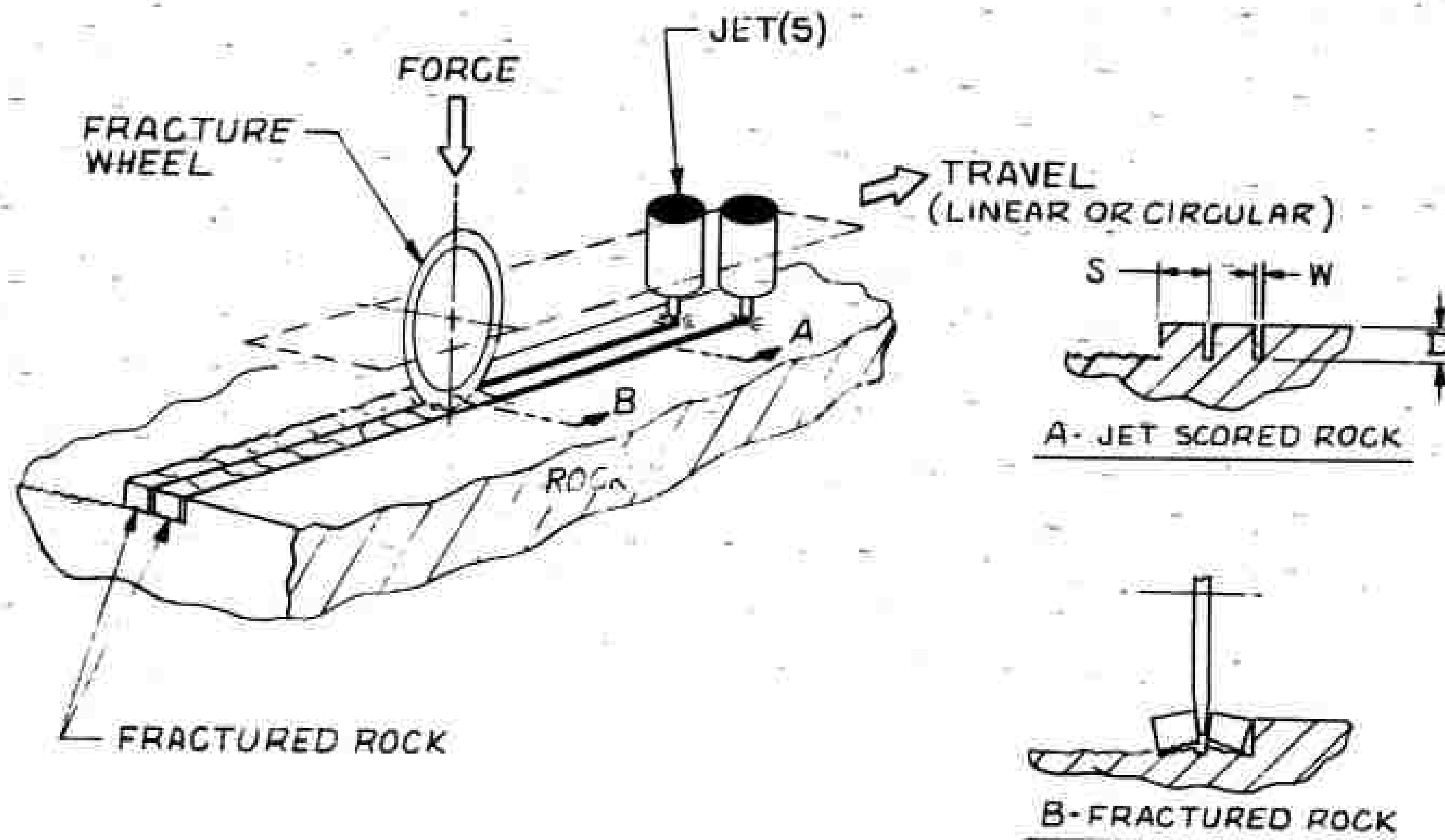

Figure 8-1 - Mechanically Assisted Fluid Jet Excavation Concept

Sandstone. In the tests described, mechanical breakage energy values were determined by dropping weights from a known height, and therefore, a known specific energy, upon wedges set in the jet kerfs, and measuring the material volume.

The strain energy, u, for breakage of a cantilever beam subjected to end loading is given as follows.[4]

$$u = \frac{1}{18} D\ S\ L \frac{(\sigma_{max})^2}{E}$$

where

σ_{max} = maximum tensile strength of the beam material

D = length of beam = depth of kerf

S = depth of beam = spacing between cuts

L = width of beam in direction of cut

Since volume removed = V = D S L

$$SE_{theo} = \frac{U}{V} = \frac{(\sigma_{max})^2}{18\ E}$$

For Berea Sandstone, $\sigma_{tensile}$ = 580 psi and E = 9.5×10^6 psi. Therefore

$$SE_{theo} = 1.9 \times 10^{-3} \text{ psi} = 1.6 \times 10^{-4} \text{ ft-lb/in}^3 = 1.4 \times 10^{-5} \text{ joules/cc}$$

for the mechanical breakage above.

The simplified case described is accurate for conditions where kerfing cuts have been completed in two directions perpendicular to each other, forming an array of free standing cantilever beams, and does not take into account the more complicated stress condition present when fracturing a rib which is fixed both at the bottom, between the cuts, and in the direction of cut, as was the case for the tests by Summers and Henry, described above. In addition, the mechanical wedge, due to friction, imparts a compressive load to the rock which tends to combat the bending load by reducing the tensile stress in the outer fiber of the cantilever beam.

A gross estimate of the actual mechanical specific energy of removal for a specific rock can be made, however, by multiplying that value recorded in the literature for Berea Sandstone by the ratio of theoretical specific energies as determined above.

For Charcoal Granite, $\sigma = 1300$ psi, $E = 9.67 \times 10^6$ psi

$$SE_{theo} = 9.7 \times 10^{-3} \text{ psi} = 8.1 \times 10^{-4} \text{ ft-lb/in}^3 = 6.69 \times 10^{-5} \text{ joules/cc}$$

For Sioux Quartzite, $\sigma = 1300$ psi, $E = 8.5 \times 10^6$ psi

$$SE_{theo} = 11. \times 10^{-3} \text{ psi} = 9.2 \times 10^{-4} \text{ ft-lb/in}^3 = 7.6 \times 10^{-5} \text{ joules/cc}$$

Data reported by Summers and Henry indicates that, for Berea Sandstone, mechanical breakage specific energies of approximately 0.5 joule/cc may be realized in removing ribs where the spacing between kerfs is approximately equal to the depth of the kerf.

The following actual specific energies therefore may be realized for mechanical breakage of other materials where the kerf spacing is equal to the kerf depths. For Charcoal Granite:

$$SE = 0.5 \times \frac{6.69 \times 10^{-5}}{1.4 \times 10^{-5}} = 2.39 \text{ joules/cc}$$

For Sioux Quartzite:

$$SE = 0.5 \times \frac{7.6 \times 10^{-5}}{1.4 \times 10^{-5}} = 2.71 \text{ joules/cc}$$

Although a correlation between jet process parameters and kerf depth was not within the scope of the present research, measurement of several test samples has shown that, at the minimum specific points used, a minimum cut depth of 0.125 inch was obtained for the hardest material, Sioux Quartzite. Cut depth generally increased with increasing supply pressure and nozzle diameter, and decreased with increasing feed-rate and rock compressive strength.

A projected overall specific energy for a mechanically assisted fluid jet excavation machine can be determined from specific energy values for each process, the kerf depth and the jet kerf volume. Specific energy and kerf volume for the jet cuts will be as determined from the minimum specific energy runs for each rock type.

For comparison of Charcoal Granite with argillites, the minimum single cut specific energy of 4248.75 joules/cc was the average value obtained for the two test runs on the Granite conducted as combination number 373. Data file ROCKS6, line 125 (presented in Appendix B) indicates that the length of cut for both test runs was 8 inches, and that kerf volumes of 0.85 and 0.9 cc, respectively, were removed. The average volume removed, therefore, was 0.875 cc for a cut length of 8 inches. Kerf depth was approximately 0.125 inch, so that, assuming a comparable spacing between kerfs, the rib volume for the 8 inch cut would be 0.125 x 0.125 x 8 = 0.125 in^3 = 2.048 cc. The two jets and cutter wheel depicted in Figure 8-1 would then remove two kerfs, having volumes of 0.875 cc each, by jet action at a specific energy of 4248.75 joules/cc, and two ribs, having volumes of 2.048 cc each, by mechanical action at 2.39 joules/cc. Total energy input would be 7444 joules to remove a total volume of 5.84 cc, therefore, the overall specific energy would be 1275 joules/cc.

The minimum single cut specific energy for Sioux Quartzite was 10,384.32 joules/cc, determined from the data for combination number 411, listed in data file ROCKS7, line 225. Cut length for this combination was 8 inches, and the average volume removed by the jet was 0.35 cc. Kerf depth was also 0.125 inch. The hybrid system would, therefore, remove 2 kerfs having volumes of 0.35 cc each by jet at 10,834.32 joules/cc, and 2 ribs having volumes of 2.048 cc each mechanically at 2.71 joules/cc. Total energy input would be 7596 joules to remove 4.796 cc of material for an overall specific energy of 1584 joules/cc.

These projected specific energy values are presented in Table 8-1 for comparison with those of the conventional and unassisted jet excavators. Since no correlation of kerf depth with jet operating parameters was completed in this program, further investigation will be required in order to determine whether lower overall specific energies can be attained by adjusting jet parameters to give greater kerf depth, thereby increasing the percentage of total material which is removed by mechanical breaking. For the jet operating parameters used, however, which were those required for minimum jet specific energy, the above analysis indicates potential minimum energy values for a hybrid jet/mechanical excavation system. Using the predicted specific energies above, a comparison between the hybrid system and a Lawrence HRT-12 excavator is presented in Table 8-2 for excavation of a 5000 foot tunnel. Horsepower for the hybrid system (using a 50 percent overall efficiency) was determined in order to equalize the penetration rates of the two systems, thereby equalizing their total operating time, direct labor costs, machine amortization costs, and the required muck removal equipment capacity. Comparisons are made on power

Table 8-2 - Operating Costs for 5000' Tunnel

Excavation System	Power (hp)	Advance Rate (ft/hr)	Cutter Cost $	Total Costs		Grand Total
				Cutter	Power	
Argillites (σ = 35000 psi)						
Lawrence HRT-12	600	5	$6.30/yd^3	$143,171	$ 16,200	$159,371
Jet/Mechanical	16450	5	$3.00/yd^3	68,176	444,139	512,315
Quartzite (σ = 50000 psi)						
Lawrence HRT-12	600	1	$9.50/yd^3	215,893	81,000	296,893
Jet/Mechanical	4096	1	$3.00/yd^3	68,176	553,035	621,211

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Volume removed $= \frac{\pi}{4}(12.5)^2 \times 5000 = 613{,}600\ ft^3 = 22{,}725\ yd^3$ Power @ $.02/KWHR = 0.027/(hp-hr)

requirements and cutter costs alone. Machine purchase, indirect overhead, roof support and material haulage costs are assumed to be equal. In both of the cases described above, however, 1.5 cc of water is required to remove either 0.366 cc of granite or 0.296 cc of quartzite, resulting in formation of a slurry of rock and water having a concentration of 40 percent or 33 percent, respectively, by weight. These concentrations are within ranges suitable for use in slurry transport by pipeline, which indicates that this mode of muck removal will be suitable for use with jet/mechanical excavators, resulting in cost benefits over systems used with present excavators. Direct maintenance costs of the excavation system itself are not considered, due to a lack of information regarding maintenance of high pressure pumping equipment. Cutter costs given are based on values given by Bruce and Morell.

As shown in Table 8-2, significant savings in cutter costs are gained by use of the hybrid jet/mechanical excavator, however, overall operating costs are higher due to power charges occasioned by the hybrid excavator's higher specific energy.

The specific energy obtained for the hybrid system does not, as mentioned previously, represent the optimum specific energy for such a system. The jet operating parameters employed in the analysis of the hybrid system specific energy were those determined for the minimum specific energy for pure jet excavation. Although no correlation between specific energy and kerf depth were included within the scope of this research, it was observed that kerf depth increased with increasing supply pressure and nozzle diameter, and decreased with increasing feedrate. The jet parameters used to obtain the minimum specific energy, therefore, also produce the smallest kerf depth.

Optimization of the specific energy of excavation for a mechanical/fluid jet excavator depends upon maximizing the proportion of material removed by mechanical action. This will require further testing to determine the jet operating parameters required to maximize jet kerf depth for a given energy input. As kerf depth is increased, the spacing between kerfs can also be increased, so that the volume of material removed by mechanical action increases with the square of the kerf depth. Since the jet excavation energy constitutes the majority of the energy input to the rock, the maximum overall efficiency for a hybrid system may be obtained at the operating parameters which produce the deepest kerf, even though the jet excavation portion of the process is not operating at its minimum specific energy.

In addition, the specific energy data determined in this program for fluid jet excavation was obtained through testing conducted upon unstressed laboratory samples. Further reduction in excavation specific energy can be expected in testing upon *in situ* rock structures due to the compressive stress field underground. Further testing will be required on *in situ* rock either in a tunnel or a quarry in order to further minimize the specific energy both for the jet excavation and the mechanical breakage processes.

Further investigation both of mechanical breakage, maximization of jet kerf depth, and interaction between the two processes both in the laboratory and *in situ* is expected to lead to the evolution of hybrid rapid excavation systems having comparable or lower specific energies than those exhibited by conventional excavators working in hard rock, with the additional advantages of reduced machine and cutter loading, increased mobility, reduced cutter costs, no dust generation and ease of integration with systems for muck removal by slurry transport.

SECTION 9

CONCLUSIONS AND RECOMMENDATIONS

- Within the experimental range employed, the minimum specific energies for single cuts were obtained at the following jet process parameters:

Pressure:	34.5 KN/cm^2 (50,000 psi)
Nozzle Dia:	0.2 mm (0.008 inch)
Feedrate:	19 cm/sec (450 ipm) for Dresser Basalt 38 cm/sec (900 ipm) for all others
Standoff:	3.81 cm (1.5 inch) for Charcoal Granite and Sioux Quartzite 1.27 cm (0.5 inch) for all others

Minimum single cut specific energies, listed in Table 7-2, ranged from 10,834 joules/cc (130,955 ft-lb/in^3 for Sioux Quartzite to 2976 joules/cc (35,977 ft-lb/in^3) for Berea Sandstone.

- Kerfing tests were conducted for each rock type using the parameters within the experimental range which produced the minimum single-cut specific energy. Specific energies for kerfing runs ranged from 6611 joules/cc, (79,900 ft-lb/in^3) for Sioux Quartzite to 1215 joules/cc (14,685 ft-lb/in^3) for Berea Sandstone, and are presented in Table 7-2.

- The kerfing run specific energies described above were found to be higher than those exhibited by conventional tunnel excavation systems described in the literature (2). The jet excavation specific energy was approximately 14 times that for a Lawrence HRT-12 excavator operating in quartzite, and 43 times the value for operation in argillites.

- A much lower machine specific energy than that for a pure jet system can be obtained in a system utilizing both jet action to cut kerfs in the rock face and mechanical devices to break the material out between the kerfs. Such a system would have the advantages of reduced machine and cutter loading, increased mobility, reduced cutter costs, no dust generation and ease of integration with systems for muck removal by slurry transport.

- Optimization of the specific energy of excavation for a mechanical/ fluid jet excavator depends upon maximizing the proportion

of material removed by mechanical action. This will require further testing to determine the jet operating parameters required to maximize jet kerf depth for a given energy input. In general, kerf depth increases with increasing nozzle diameter and supply pressure, and the volume of material removed by mechanical action increases with the square of the kerf depth. Since the jet excavation energy constitutes the majority of the energy input to the rock, the maximum overall efficiency for a hybrid system may be obtained at the operating parameters which produce the deepest kerf, even though the jet excavation portion of the process is not operating at its minimum specific energy.

- Mechanical breakage energies should be determined for harder rock structures both in the laboratory and *in situ* for eventual incorporation in the design of a mechanically assisted fluid jet excavator. Relationships between specific energy, kerf depth and spacing between kerfs should be explored in detail.
- Further investigation is recommended to determine jet excavator performance upon *in situ* rock structures rather than upon unstressed laboratory specimens. Lower specific energies of excavation can be expected for *in situ* rock since the compressive stress field underground favors rock fracturing by the jet kerfing mode.
- Development of a mobile excavation test rig should be completed to facilitate *in situ* testing both in tunnels and quarries. The device should include both jet and mechanical modes of rock fracturing, allowing it to be used for investigation of operating parameters required for a hybrid jet/mechanical excavation system. Pressure and flow capabilities of the jet excavation portion should be comparable to those used in the present test program, that is, 80,000 psi and 1.4 GPM, allowing the device to be used for investigations regarding specific energy minimization or kerf depth maximization; provision should also be included for mounting various mechanical fracturing devices to determine relative effectiveness of each.

SECTION 10

REFERENCES

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APPENDIX A

SUMMARY OF ROCK PROPERTIES

CHARCOAL GRANITE

TYPE NO. 1

Property	Test Results (English Units)	Test Results (SI Units)
Compressive strength	35.1×10^3 lb/in^2	244 MN/m^2
Density (apparent)	170.5 lb/ft^3	2.72 g/cm^3
Hardness (Shore scleroscope)	95	95
Poisson's ratio (dynamic)	0.28	0.28
Tensile strength (pull)	1300 lb/in^2	9 MN/m^2
Tensile strength (indirect)	1570 lb/in^2	12.8 MN/m^2
Young's modulus (dynamic)	9.67×10^6 lb/in^2	66.7 GN/m^2
Young's modulus (static)	9.3×10^6 lb/in^2	64.1 GN/m^2

WESTERLY GRANITE

TYPE NO. 2

Property	Test Results (English Units)	Test Results (SI Units)
Density (apparent)	165 lb/ft^3	2.64 g/cm^3
Poisson's ratio (dynamic)		0.24
Poisson's ratio (static)		0.20
Shear modulus (dynamic)	2.6-4.6 x 10^6 lb/in^2	18-32 GN/m^2
Shear modulus (static)	3.83 x 10^6 lb/in^2	26.4 GN/m^2
Velocity (longitudinal pulse)	1955 ft/sec x10^3	5930 m/sec x 10^3
Velocity (shear)	11,000 ft/sec x 10^3	3360 m/sec x 10^3
Young's modulus (dynamic)	5.8-11.6 x 10^6 lb/in^2	39.9-80 GN/m^2
Young's modulus (static)	8.26 x 10^6 lb/in^2	56.9 GN/m^2

BARRE GRANITE

TYPE NO. 3

Property	Test Results (English Units)	Test Results (SI Units)
Compressive strength	23.9×10^3 lb/in^2	167 MN/m^2
Density (apparent)	166 lb/ft^3	2.66 g/cm^3
Shear modulus (dynamic)	2.44×10^6 lb/in^2	16.8 GN/m^2
Shear modulus (static)	$2.2\text{-}2.4 \times 10^6$ lb/in^2	15.2-16.9 GN/m^2
Young's modulus (dynamic)	4.41×10^6 lb/in^2	30.4 GN/m^2
Young's modulus (static)	$3.96\text{-}6.41 \times 10^6$ lb/in^2	27.3-44.2 GN/m^2

DRESSER BASALT

TYPE NO. 4

Property	Test Results (English Units)	Test Results (SI Units)
Compressive strength	50×10^3 lb/in^2	350 MN/m^2
Density (apparent)	187 lb/ft^3	2.99 g/cm^3
Hardness (Shore scleroscope)	90	90
Poisson's ratio (dynamic)	0.285	0.285
Porosity	0.20 percent	
Shear modulus (dynamic)	5.85×10^6 lb/in^2	40 GN/m^2
Tensile strength (pull)	2100 lb/in^2	14 MN/m^2
Tensile strength (indirect)	2750 lb/in^2	19 MN/m^2
Velocity (longitudinal bar)	19.1 ft/sec $\times 10^3$	5.82 m/sec $\times 10^3$
Velocity (longitudinal pulse)	21.7 ft/sec $\times 10^3$	6.62 m/sec $\times 10^3$
Velocity (shear)	11.9 ft/sec $\times 10^3$	3.63 m/sec $\times 10^3$
Young's modulus (dynamic)	14.5×10^6 lb/in^2	100 GN/m^2
Young's modulus (static)	12.5×10^6 lb/in^2	86.2 GN/m^2

SIOUX QUARTZITE

TYPE NO. 5

Property	Test Results (English Units)	Test Results (SI Units)
Compressive strength	54×10^3 lb/in^2	350 MN/m^2
Density (apparent)	150 lb/ft^3	2.39 g/cm^3
Hardness (Shore scleroscope)	99	89
Poisson's ratio (dynamic)	0.13-0.28	0.13-0.28
Porosity	<1 percent	
Shear modulus (dynamic)	$4.2\text{-}5.0 \times 10^6$ lb/in^2	29-35 GN/m^2
Tensile strength (pull)	1300 lb/in^2	9 MN/m^2
Tensile strength (indirect)	2900 lb/in^2	20 MN/m^2
Velocity (longitudinal bar)	14.6 ft/sec $\times 10^3$	4.45 m/sec $\times 10^3$
Velocity (longitudinal pulse)	16.2 ft/sec $\times 10^3$	4.9 m/sec $\times 10^3$
Velocity (shear)	11.0 ft/sec $\times 10^3$	3.35 m/sec $\times 10^3$
Young's modulus (dynamic)	8.5×10^6 lb/in^2	58 GN/m^2
Young's modulus (static)	10.1×10^6 lb/in^2	69.6 GN/m^2

BEREA SANDSTONE

TYPE NO. 6

Property	Test Results (English Units)	Test Results (SI Units)
Compressive strength	8.6×10^3 lb/in^2	59 MN/m^2

TENNESSEE MARBLE

TYPE NO. 7

Property	Test Results (English Units)	Test Results (SI Units)
Compressive strength	16.9×10^3 lb/in^2	118 MN/m^2
Density (apparent)	167 lb/ft^3	2.69 g/cm^3
Hardness (Shore scleroscope)	56.5	56.5
Poisson's ratio (dynamic)	0.292	0.292
Shear modulus (dynamic)	4.2×10^6 lb/in^2	28.8 GN/m^2
Tensile strength (pull)	1300 lb/in^2	9.2 MN/m^2
Tensile strength (indirect)	745 lb/in^2	5.13 MN/m^2
Velocity (longitudinal bar)	16,850 ft/sec $\times 10^3$	5140 m/sec $\times 10^3$
Velocity (longitudinal pulse)	20,050 ft/sec $\times 10^3$	6100 m/sec $\times 10^3$
Velocity (shear)	10,600 ft/sec $\times 10^3$	3140 m/xec $\times 10^3$
Young's modulus (dynamic)	10.6×10^6 lb/in^2	73.0 GN/m^2
Young's modulus (static)	9.0×10^6 lb/in^2	62.0 GN/m^2

SALEM LIMESTONE

TYPE NO. 8

Property	Test Results (English Units)	Test Results (SI Units)
Compressive strength	9.5×10^3 lb/in^2	65.9 MN/m^2
Density (apparent)	149 lb/ft^3	2.39 g/cm^3
Hardness (Shore scleroscope)	29.5	29.5
Poisson's ratio (dynamic)	0.299	0.299
Shear modulus (dynamic)	2.2×10^6 lb/in^2	15.2 GN/m^2
Tensile strength (pull)	580 lb/in^2	3.9 MN/m^2
Velocity (longitudinal bar)	12,550 ft/sec $\times 10^3$	3800 m/sec $\times 10^3$
Velocity (longitudinal pulse)	14,550 ft/sec $\times 10^3$	4447 m/sec $\times 10^3$
Velocity (shear)	10,000 ft/sec $\times 10^3$	3000 m/sec $\times 10^3$
Young's modulus (dynamic)	4.8×10^6 lb/in^2	34.2 GN/m^2
Young's modulus (static)	3.92×10^6 lb/in^2	27.2 GN/m^2

APPENDIX B

COMPUTER PROGRAMS AND DATA SUMMARY

ENERGY

```
PRØGRAM LANGUAGE: FØRTRAN (FØR)
INPUT FILE FØRMAT: CØMBINATIØN #,TEST #,SAMPLE #,PRESSURE
(50000=-1,65000=0,80000=1),FEEDRATE(50=-1,100=0,150=1),
STANDØFF(.5=-1,1.0=0,1.5=1),NØZZLE(.008=-1,.012=0,.0136=1),
LENGTH ØF CUT(IN.),VØLUME REMØVED(CUBIC CM.)
$FILE (LIST ØUTPUT FILES #1,....,#8,INPUT FILES #9,....)
DIMENSIØNSE(100),SJ(100),SP(100),SB(100)
REAL L
25 FØRMAT(56H2↑4 FACTØRIAL FRAGMENTATIØN TEST DATA, RØCK TY
 +PE NUMBER:,I4)
30 FØRMAT(68HCØMB.   TEST   SAMPLE      TREATMENT CØMBINATIØN
 +                  SPECIFIC)
35 FØRMAT(67H  #        #        #     PRESSURE    RATE  STAND
 +ØFF  NØZZLE        ENERGY)
36 FØRMAT(53H                                P         F         S
 +            N)
40 FØRMAT(I4,I8,I6,I11,I8,F8.1,F10.4,F15.2)
50 FØRMAT(I29,I8,F8.1,F10.4,F15.2)
60 FØRMAT(F11.2,F19.2,F19.2)
N=0
B=0
J=1
K=9
I=0
A=2
CI=0
90 READ (K)J
IF(J)410,410,95
95 PRINT 25,J
PRINT
PRINT
PRINT 30
PRINT 35
PRINT 36
PRINT
100 READ (K)C
IF (C)410,340,105
105 IF(C-CI) 112,112,106
106 IF(A-1)107,107,110
107 B=B+1
SB(B)=SE(I)
110 A=0
112 READ (K) T,R,P,F,S,D,L,V
IF(1-P)155
IF(P)120,130,140
120 P=50000
GØTØ155
130 P=65000
GØTØ155
140 P=80000
```

ENERGY CONTINUED

```
350 155 IF(1-F)195
355 IF(F)160,170,180
360 160 F=50
365 GOTO195
370 170 F=100
375 GOTO195
380 180F=150
385 195 IF(S)200,210,220
390 200 S=.5
395 GOTO230
400 210 S=1.0
405 GOTO230
410 220 S=1.5
415 230 IF(D)240,250,260
420 240 D=.008
425 GOTO285
430 250 D=.012
435 GOTO285
440 260 D=.0136
445 285 I=I+1
450 B=B+1
455 SE(I)=7059.173*D**2*P*SQRT(P)*L/F/V
460 SB(B)=SE(I)
465 A=A+1
470 IF(C-CI)300,290,300
475 290 PRINT50,P,F,S,D,SE(I)
480 GOTO310
485 300 PRINT40,C,T,R,P,F,S,D,SE(I)
490 310 CI=C
495 GOTO100
500 340 PRINT
505 PRINT
510 PRINT
515 IF(A-1)342,342,343
520 342 B=B+1
525 SB(B)=SE(I)
530 343 PRINT"            SPECIFIC ENERGY"
535 PRINT
540 PRINT"FT.-LB./CU.IN.      JOULES/CU.CM.           PSI"
545 PRINT
550 N=I
555 DO390I=1,N
560 SJ(I)=.082733*SE(I)
565 SP(I)=12*SE(I)
570 390 PRINT60,SE(I),SJ(I),SP(I)
575 P=B
580 REWINDJ
585 DO 395B=1,P
590 395 WRITE(J)SB(B)
595 J=J+1
```

ENERGY CØNTINUED

```
600 N=0
605 A=2
610 I=0
615 B=0
620 CI=0
625 PRINT
630 PRINT
635 PRINT
640 PRINT
645 IF (ENDFILEK)405,400
650 400 K=K+1
655 405 GØTØ90
660 410 END
```

ANØVA

```
100 PRØGRAM LANGUAGE: ADVANCED BASIC (XBAS)
105 FILES (LIST INPUT FILES #1;....;#8)
110 LET Q1=1
115 PRINT
120 PRINT
125 PRINT
130 PRINT
135 PRINT"ANALYSIS ØF VARIANCE, RØCK TYPE NUMBER:",Q1
140 PRINT
145 PRINT
150 PRINT"                    MEAN SPECIFIC ENERGY VALUES"
155 PRINT
160 PRINT
165 PRINT"CØMBINATIØN #","MEAN SPECIFIC ENERGY (FT.-LB./CU.IN.)"
170 DIM X(100)
175 DIM Q(100)
180 DIM S(100)
185 DIM A(100)
190 DIM C(100)
195 DIM U(100)
200 DIM P(100)
205 DIM Z(64,6)
210 MAT Z= ZER
215 LET N=(INPUT: NUMBER ØF VARIABLES)
220 LET R=(INPUT: NUMBER ØF REPLICATIØNS)
225 LET V=0
230 LET A(1)=0
235 LET A(2)=0
240 FØR X = 1 TØ2↑N
245 LET W=0
250 FØR K =1 TØ R
255 READ # Q1,X(K)
260 LET S(K)=X(K)+A(K)
265 LET A(K)=S(K)
270 LET W=X(K)+W
275 LET V=X(K)↑2+V
280 LET Z=X(K)+Z
285 NEXT K
290 LET C(X)=W
295 LET Q2=(INPUT: STATEMENT FØR CØMBINATIØN NUMBER)
300 IF R=1 THEN 310
305 PRINT  Q2,C(X)/R
310 NEXTX
315 DEF FNX(X)=(X+1)/2
320 DEF FNY(X)=(X+1)/2+(2↑N/2)
325 FØR J =1 TØ N
330 FØRX=1 TØ 2↑N STEP 2
335 LET P(FNX(X))=C(X)+C(X+1)
340 LET P(FNY(X))=C(X+1)-C(X)
345 NEXT X
```

```
350 FØR X=1 TØ2↑N
355 LET C(X)=P(X)
360 NEXT X
365 NEXT J
370 LET L=0
375 FØR X=2 TØ 2↑N
380 LET U(X)=C(X)↑2/(R*2↑N)
385 LET L=(C(X)↑2/(R*2↑N))+L
390 NEXT X
395 FØR I = 1 TØ N
400 LET K=I-1
405 FØR S =(2↑K)+1 TØ 2↑N STEP 2↑I
410 FØR J=S TØ (S+(2↑K-1))
415 LET Z(J,I)=1
420 NEXT J
425 NEXT S
430 NEXT I
435 IF R=1 THEN 460
440 LET B=(A(1)↑2+A(2)↑2)/2↑N-(C(1)↑2/(R*2↑N))
445 LET E=V-(C(1)↑2/(R*2↑N))-L-B
450 LET D=(2↑N*(R-1))-1
455 LET M=E/D
460 PRINT
465 PRINT
470 PRINT "                    ANALYSIS ØF VARIANCE TABLE"
475 PRINT
480 PRINT
485 IF R=1 THEN 595
490 PRINT"SØURCE ØF","SUMS ØF","DF","F RATIØ","TREATMENT"
495 PRINT"VARIATIØN","SQUARES"," "," ","EFFECTS"
500 FØR X=2 TØ 2↑N
505 GØSUB 645
510 LET Q(X)=C(X)/(R*2↑(N-1))
515 PRINT " ",U(X),"1",U(X)/M,Q(X)
520 NEXT X
525 PRINT
530 PRINT "REPLICATE",B,(R-1),B/(M*(R-1))
535 PRINT
540 PRINT "ERRØR",E,D
545 PRINT
550 PRINT "TØTAL",V-(C(1)↑2/(R*2↑N)),2↑N*R-1
555 PRINT
560 PRINT "ERRØR MEAN SQUARE=",M
565 LET G=SQR(M)/SQR(R)
570 PRINT
575 PRINT G;"IS THE SQUARE RØØT ØF THE RATIØ ØF THE MEAN"
580 PRINT "SQUARE ERRØR TØ THE NUMBER ØF REPLICATIØNS PER CELL."
590 GØ TØ 625
595 PRINT "SØURCE ØF","SUMS ØF"
600 PRINT "VARIATIØN","SQUARES"
```

ANØVA CØNTINUED

```
605 FØR X=2 TØ 2↑N
610 GØSUB 645
615 PRINT " ",U(X)
620 NEXT X
625 PRINT
630 LET Q1=Q1+1
635 IF(INPUT: CRITERIA FØR NØT ENDING PRØGRAM)THEN115
640 STØP
645 IF Z(X,1)=1 THEN 670
650 IF Z(X,2)=1 THEN 680
655 IF Z(X,3)=1 THEN 690
660 IF Z(X,4)=1 THEN 700
665 GØ TØ 705
670 PRINT "P";
675 GØ TØ 650
680 PRINT "F";
685 GØ TØ 655
690 PRINT "S";
695 GØ TØ 660
700 PRINT "N";
705 RETURN
710 STØP
715 DATA 0
720 END
```

KERF

```
PR0GRAM LANGUAGE: F0RTRAN (FOR)
$FILE R0CKS8
DIMENSI0N SE(4,10),SM(4,10),SUM(4),A(4),DIF(4),DIFM(4)
REAL L
10 F0RMAT(50HKERFING FRAGMENTATI0N TEST DATA, R0CK TYPE
+ NUMBER:,I4)
15 F0RMAT(20H                PRESSURE =,I6,6H PSI =,F9.2,15H NEWT0NS
+/SQ.CM.)
20 F0RMAT(20H                FEEDRATE =,I6,6H IPM =,F6.2,9H CM./SEC.)
25 F0RMAT(20H                STAND0FF =,F6.1,6H IN. =,F6.3,4H CM.)
30 F0RMAT(20H               N0ZZLE   =,F6.4,6H IN. =,F6.5,4H MM.)
35 F0RMAT(32H                SPACING BETWEEN CUTS =,F5.3,6H IN. =,
+F5.3,4H CM.)
70 F0RMAT(56H        CUT NUMBER           AVERAGE SPECIFIC ENERGY
+PER CUT)
75 F0RMAT(57H                             FT.LB./CU.IN.
+J0ULES/CU.CM.)
80 F0RMAT(I10,F24.2,F20.2)
90 F0RMAT(14H         AVERAGE,2F20.2)
40 F0RMAT(56HC0MB.    TEST    SAMPLE    NUMBER            SP
 +ECIFIC ENERGY)
45 F0RMAT(68H   #         #       #      0F CUTS   FT.LB./CU.
+IN.        J0ULES/CU.CM.)
50 F0RMAT(I4,I9,I7,I8,F17.2,F20.2)
60 F0RMAT(I20,I8,F17.2,F20.2)
95 READ(1)J
X1=0
IF(J)300,300,100
100 READ(1)P,F,S,D,Q
P1=.68966*P
F1=.04233333*F
S1=2.54*S
D1=D*25.4
Q1=2.54*Q
PRINT10,J
PRINT
PRINT
PRINT15,P,P1
PRINT20,F,F1
PRINT 25,S,S1
PRINT 30,D,D1
PRINT
PRINT 35,Q,Q1
PRINT
PRINT
PRINT 40
PRINT 45
PRINT
120 READ(1)C
IF(C)180,180,125
```

```
350 125 READ(1)T,R,L,V,X
355 IF(X-X1)135,135,130
360 130 Y=1
365 135 SE(X,Y)=7059.173*D**2*P*SQRT(P)*X*L/F/V
370 SM(X,Y)=.082733*SE(X,Y)
375 IF(X-X1)150,150,140
380 140 PRINT 50,C,T,R,X,SE(X,Y),SM(X,Y)
385 X1=X
390 GØTØ160
395 150 IF(R-R1)160,160,155
400 155 PRINT 60,R,X,SE(X,Y),SM(X,Y)
405 160 A(X)=Y
410 Y=Y+1
415 GØTØ120
420 180 PRINT
425 PRINT
430 DØ230 X=1,3
435 SUM(X)=0
440 Z=A(X)
445 DØ 220Y=1,Z
450 220 SUM(X)=SE(X,Y)+SUM(X)
455 230 SUM(X)=SUM(X)/A(X)
460 X=1
465 PRINT 70
470 DIF(X)=SUM(X)
475 DIFM(X)=.082733*SUM(X)
480 PRINT 75
485 PRINT
490 PRINT 80,X,DIF(X),DIFM(X)
495 DØ250X=2,3
500 DIF(X)=X/SUM(X)-(X-1)/SUM(X-1)
505 DIF(X)=1/DIF(X)
510 DIFM(X)=.082733*DIF(X)
515 PRINT
520 250 PRINT 80,X,DIF(X),DIFM(X)
525 PRINT
530 DIFA=(DIF(2)+DIF(3))/2
535 DIFB=(DIFM(2)+DIFM(3))/2
540 PRINT 90,DIFA,DIFB
545 PRINT
550 PRINT
555 PRINT
560 PRINT
565 GØTØ95
570 300 END
```

RØCKS1

```
100 $DATA'2↑4 FACTØRIAL FRAGMENTATIØN TEST INPUT DATA'
105 $DATA'CHARCØAL GRANITE'
110 1
115 1,25,12,-1,-1,-1,-1,8.0,1.1,1,25,12,-1,-1,-1,-1,8.0,1.0
120 2,48,2,1,-1,-1,-1,8.1,1.1,2,48,2,1,-1,-1,-1,8.1,1.2
125 3,38,19,-1,1,-1,-1,8.0,1.2,3,38,19,-1,1,-1,-1,8.,.8
130 4,28,5,1,1,-1,-1,8.05,.95,4,28,5,1,1,-1,-1,8.05,1.0
135 5,15,13,-1,-1,1,-1,8.0,1.1,5,15,13,-1,-1,1,-1,8.0,1.4
140 6,46,15,1,-1,1,-1,7.95,1.5,6,46,15,1,-1,1,-1,7.95,1.3
145 7,17,1,-1,1,1,-1,7.95,1.,7,17,1,-1,1,1,-1,7.95,.9
150 8,32,14,1,1,1,-1,8.0,.4,8,32,14,1,1,1,-1,8.,.3
155 9,77,20,-1,-1,-1,1,8.,2.5,9,77,20,-1,-1,-1,1,8.,2.3
160 10,104,16,1,-1,-1,1,7.9,1.2
165 10,104,16,1,-1,-1,1,7.9,1.0,11,102,6,-1,1,-1,1,7.9,.6
170 11,102,6,-1,1,-1,1,7.9,.8,12,111,3,1,1,-1,1,8.,1.,12
175 102,3,1,1,-1,1,8.,1.1,13,70,7,-1,-1,1,1,7.95,1.9
180 13,70,7,-1,-1,1,1,7.95,1.9,14,86,9,1,-1,1,1,8.06,1.5
185 14,86,9,1,-1,1,1,8.06,1.6,15,87,11,-1,1,1,1,7.95,.8
190 15,87,11,-1,1,1,1,7.95,1.,16,105,8,1,1,1,1,8.,1.1
195 16,105,8,1,1,1,1,8.,1.
200 0
205 $DATA'WESTERLY GRANITE'
210 2
215 17,18,2,-1,-1,-1,-1,7.85,1.,17,18,2,-1,-1,-1,-1,7.85,1.
220 18,7,5,1,-1,-1,-1,7.9,1.4,19,8,4,-1,1,-1,-1,8.1,.6
225 20,51,3,1,1,-1,-1,8.,1.,20,51,3,1,1,-1,-1,8.,1.1
230 21,3,1,-1,-1,1,-1,7.9,.8,22,5,3,1,-1,1,-1,8.,1.4
235 22,5,3,1,-1,1,-1,8.,1.4,23,23,5,-1,1,1,-1,7.95,.9
240 23,23,5,-1,1,1,-1,7.95,.6,24,20,1,1,1,1,-1,6.,.8
245 24,20,1,1,1,1,-1,6.,.65,25,96,4,-1,-1,-1,1,8.1,.8
250 25,96,4,-1,-1,-1,1,8.1,1.1,26,92,2,1,-1,-1,1,7.85,2.0
255 26,92,2,1,-1,-1,1,7.85,1.9,27,124,1,-1,1,-1,1,8.,.5
260 27,124,1,-1,1,-1,1,8.,.5,28,72,2,1,1,-1,1,7.95,3.2
265 28,72,2,1,1,-1,1,7.95,3.1,29,123,3,-1,-1,1,1,8.,.95
270 29,123,3,-1,-1,1,1,8.,.8,30,91,4,1,-1,1,1,8.1,1.5
275 30,91,4,1,-1,1,1,8.1,1.5,31,113,1,-1,1,1,1,7.9,.8
280 31,113,1,-1,1,1,1,7.9,.5,32,121,5,1,1,1,1,8.,1.
285 32,121,5,1,1,1,1,8.,1.1
290 0
295 $DATA'BARRE GRANITE'
300 3
305  33,11,7,-1,-1,-1,-1,8.15,.8,33,11,7,-1,-1,-1,-1,8.15,.8
310 +34,13,17,1,-1,-1,-1,8.2,1.3,34,13,17,1,-1,-1,-1,8.2,1.3
315 +35,22,11,-1,1,-1,-1,8.2,.9,35,22,11,-1,1,-1,-1,8.2,1.0
320 +36,43,10,1,1,-1,-1,8.2,1.35,36,43,10,1,1,-1,-1,8.2,1.0
325 +37,50,19,-1,-1,1,-1,8.2,.8,37,50,19,-1,-1,1,-1,8.2,.9
330 +38,31,1,1,-1,1,-1,8.2,1.2,38,31,1,1,-1,1,-1,8.2,1.2
335 +39,19,3,-1,1,1,-1,8.15,.3,39,19,3,-1,1,1,-1,8.15,.5
340 +40,37,2,1,1,1,-1,8.1,1.0,40,37,2,1,1,1,-1,8.1,.95
345 +41,81,6,-1,-1,-1,1,7.95,2.6,41,81,6,-1,-1,-1,1,7.95,2.7
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RØCKS1 CØNTINUED

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350 +42,76,8,1,-1,-1,1,8.0,4.4,42,76,8,1,-1,-1,1,8.0,4.4
355 +43,89,16,-1,1,-1,1,7.9,.7
360 +43,89,16,-1,1,-1,1,7.9,.7
365 +44,68,20,1,1,-1,1,7.5,3.0,44,68,20,1,1,-1,1,7.5,2.8
370 +45,82,18,-1,-1,1,1,8.0,2.3,45,82,18,-1,-1,1,1,8.0,2.0
375 +46,85,4,1,-1,1,1,8.0,1.4,46,85,4,1,-1,1,1,8.0,1.4
380 +47,74,5,-1,1,1,1,8.0,1.6,47,74,5,-1,1,1,1,8.0,1.8
385 +48,100,14,1,1,1,1,8.0,1.0,48,100,14,1,1,1,1,8.0,1.2
390 0
395 $DATA'DRESSER BASALT'
400 4
405 49,54,14,-1,-1,-1,-1,6.0,2.0
410 50,34,19,1,-1,-1,-1,6.0,6.1,50,34,19,1,-1,-1,-1,6.0,3.6
415 51,29,8,-1,1,-1,-1,6.0,1.5,51,29,8,-1,1,-1,-1,6.0,.8
420 52,41,1,1,1,-1,-1,5.0,8.0,53,57,3,-1,-1,1,-1,6.0,1.4
425 54,58,12,1,-1,1,-1,6.0,5.8,55,9,20,-1,1,1,-1,6.05,1.1
430 55,9,20,-1,1,1,-1,6.05,1.0,56,35,5,1,1,1,-1,6.15,1.4
435 57,94,13,-1,-1,-1,1,6.1,1.6,57,94,13,-1,-1,-1,1,6.1,1.5
440 58,75,6,1,-1,-1,1,4.125,5.0,59,109,2,-1,1,-1,1,7.95,2.0
445 59,109,2,-1,1,-1,1,7.95,2.7,60,106,10,1,1,-1,1,5.3,4.6
450 60,106,10,1,1,-1,1,5.7,3.4,61,116,15,-1,-1,1,1,5.5,1.22
455 61,116,15,-1,-1,1,1,5.6,1.3,62,90,16,1,-1,1,1,4.55,.7
460 62,90,16,1,-1,1,1,4.5,.6,63,117,7,-1,1,1,1,5.75,1.8
465 63,117,7,-1,1,1,1,5.75,1.5,64,67,17,1,1,1,1,5.25,9.8
470 0
475 $DATA'SIØUX QUARTZITE'
480 5
485 65,24,10,-1,-1,-1,-1,9.6,.9,65,24,10,-1,-1,-1,-1,9.6,1.1
490 66,36,2,1,-1,-1,-1,10.0,1.8,66,36,2,1,-1,-1,-1,10.0,1.5
495 67,21,20,-1,1,-1,-1,9.5,1.2,67,21,20,-1,1,-1,-1,9.6,1.1
500 68,42,3,1,1,-1,-1,9.25,1.2,68,42,3,1,1,-1,-1,10.2,1.1
505 69,60,8,-1,-1,1,-1,7.9,.7,69,60,8,-1,-1,1,-1,7.9,.8
510 70,26,18,1,-1,1,-1,9.5,1.1,70,26,18,1,-1,1,-1,9.5,1.25
515 71,4,4,-1,1,1,-1,10.0,.7,71,4,4,-1,1,1,-1,11.25,.8
520 72,16,7,1,1,1,-1,11.8,1.0,72,16,7,1,1,1,-1,11.8,.8
525 73,65,5,-1,-1,-1,1,10.0,2.8,73,65,5,-1,-1,-1,1,10.0,2.8
530 74,88,13,1,-1,-1,1,10.0,1.5,74,88,13,1,-1,-1,1,10.0,1.6
535 75,73,1,-1,1,-1,1,7.7,1.6,75,73,1,-1,1,-1,1,9.7,1.7
540 76,126,12,1,1,-1,1,9.2,1.3,76,126,12,1,1,-1,1,9.2,1.
545 77,83,6,-1,-1,1,1,8.4,1.8,77,83,6,-1.-1,1,1,8.9,2.3
550 78,71,17,1,-1,1,1,9.0,3.25,78,71,17,1,-1,1,1,9.0,3.25
555 79,93,11,-1,1,1,1,10.8,.8,79,93,11,-1,1,1,1,10.8,.9
560 80,98,16,1,1,1,1,10.8,1.0,80,98,16,1,1,1,1,10.8,1.0
565 0
570 $DATA'BEREA SANDSTØNE'
575 6
580 81,6,9,-1,-1,-1,-1,7.9,2.6,81,6,9,-1,-1,-1,-1,7.9,2.9
585 82,53,13,1,-1,-1,-1,8.,7.8,82,53,13,1,-1,-1,-1,8.,7.6
590 83,55,4,-1,1,-1,-1,8.,4.,83,55,4,-1,1,-1,-1,8.,4.
595 84,14,17,1,1,-1,-1,8.,5.1,84,14,17,1,1,-1,-1,8.,5.3
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RØCKS1 CØNTINUED

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600 85,1,18,-1,-1,1,-1,8.,3.2,85,1,18,-1,-1,1,-1,8.,3.8
605 86,2,14,1,-1,1,-1,8.,7.5,86,2,14,1,-1,1,-1,8.,7.8
610 87,10,2,-1,1,1,-1,8.05,2.5,87,10,2,-1,1,1,-1,8.05,2.7
615 88,61,1,1,1,1,-1,8.05,4.7,88,61,1,1,1,1,-1,8.05,4.5
620 89,110,11,-1,-1,-1,1,8.,3.2,89,110,11,-1,-1,-1,1,8.,3.6
625 90,118,10,1,-1,-1,1,8.,7.2,90,118,10,1,-1,-1,1,8.,6.4
630 91,103,5,-1,1,-1,1,8.,2.4,91,103,5,-1,1,-1,1,8.,2.6
635 92,80,12,1,1,-1,1,8.05,20.7,92,80,12,1,1,-1,1,8.05,18.1
640 93,107,16,-1,-1,1,1,8.,3.4,93,107,16,-1,-1,1,1,8.,3.2
645 94,97,15,1,-1,1,1,7.95,5.5,94,97,15,1,-1,1,1,7.95,5.4
650 95,99,3,-1,1,1,1,8.,2.5,95,99,3,-1,1,1,1,8.,2.75
655 96,84,6,1,1,1,1,8.,17.9,96,84,6,1,1,1,1,8.,15.6
660 0
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ROCKS2

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100 $DATA'2↑4 FACTØRIAL FRAGMENTATIØN TEST INPUT DATA'
105 $DATA'TENNESSEE MARBLE'
110 7
115 97,59,6,-1,-1,-1,-1,8.0,1.3,97,59,6,-1,-1,-1,-1,8.0,1.2
120 98,47,20,1,-1,-1,-1,8.0,1.3,98,47,20,1,-1,-1,-1,8.0,1.3
125 99,64,11,-1,1,-1,-1,8.0,.85,99,64,11,-1,1,-1,-1,8.0,.85
130 100,12,1,1,1,-1,-1,8.05,.8,100,12,1,1,1,-1,-1,8.05,.7
135 101,63,4,-1,-1,1,-1,8.0,1.9,101,63,4,-1,-1,1,-1,8.0,1.3
140 102,49,7,1,-1,1,-1,8.0,.8,102,49,7,1,-1,1,-1,8.0,1.0
145 103,39,3,-1,1,1,-1,8.1,.8,103,39,3,-1,1,1,-1,8.1,1.6
150 104,62,18,1,1,1,-1,8.1,.9,104,62,18,1,1,1,-1,8.1,.7
155 105,108,13,-1,-1,-1,1,8.0,.5,105,108,13,-1,-1,-1,1,8.0,1.0
160 106,79,19,1,-1,-1,1,8.1,3.1,106,79,19,1,-1,-1,1,8.1,2.9
165 107,66,9,-1,1,-1,1,8.1,1.3,107,66,9,-1,1,-1,1,8.1,1.8
170 108,125,8,1,1,-1,1,8.0,.9,108,125,8,1,1,-1,1,8.0,.9
175 109,112,10,-1,-1,1,1,8.0,1.6,109,112,10,-1,-1,1,1,8.0,2.0
180 110,119,17,1,-1,1,1,7.9,1.2,110,119,17,1,-1,1,1,7.9,1.1
185 111,122,2,-1,1,1,1,7.95,1.5,111,122,2,-1,1,1,1,7.95,1.8
190 112,127,15,1,1,1,1,8.1,.7,112,127,15,1,1,1,1,8.1,.7
195 0
200 $DATA'SALEM LIMESTØNE'
205 8
210 113,27,13,-1,-1,-1,-1,8.1,2.5,113,27,13,-1,-1,-1,-1,8.1,2.2
215 114,30,3,1,-1,-1,-1,8.1,16.8,114,30,3,1,-1,-1,-1,8.1,8.5
220 115,44,10,-1,1,-1,-1,8.,1.,115,44,10,-1,1,-1,-1,8.,1.1
225 116,33,9,1,1,-1,-1,8.1,2.7,116,33,9,1,1,-1,-1,8.1,3.2
230 117,52,4,-1,-1,1,-1,8.,1.,117,52,4,-1,-1,1,-1,8.,.9
235 118,40,11,1,-1,1,-1,8.,2.4,118,40,11,1,-1,1,-1,8.,2.5
240 119,45,1,-1,1,1,-1,8.,1.1,119,45,1,-1,1,1,-1,8.,1.3
245 120,56,15,1,1,1,-1,8.05,1.6,120,56,15,1,1,1,-1,8.05,1.4
250 121,69,14,-1,-1,-1,1,8.1,18.,121,69,14,-1,-1,-1,1,8.1,17.4
255 122,95,17,1,-1,-1,1,7.95,1.2,122,95,17,1,-1,-1,1,7.95,2.9
260 123,101,18,-1,1,-1,1,8.1,1.8,123,101,18,-1,1,-1,1,8.1,2.1
265 124,120,5,1,1,-1,1,8.,3.1,124,120,5,1,1,-1,1,8.,3.
270 125,115,19,-1,-1,1,1,8.1,1.8,125,115,19,-1,-1,1,1,8.1,1.75
275 126,114,2,1,-1,1,1,8.,5.1,126,114,2,1,-1,1,1,8.,5.9
280 127,128,6,-1,1,1,1,8.09,1.5,127,128,6,-1,1,1,1,8.09,1.6
285 128,78,12,1,1,1,1,8.05,12.1,128,78,12,1,1,1,1,8.05,13.7
290 0
295 -1
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RØCKS3

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100 $DATA'3↑2 FACTØRIAL FRAGMENTATIØN TEST INPUT DATA'
105 $DATA'CHARCØAL GRANITE'
110 1
115 140,38,19,-1,1,-1,-1,8.,1.2,140,38,19,-1,1,-1,-1,8.,.8
120 141,144,17,0,1,-1,-1,8.,.5,141,144,17,0,1,-1,-1,8.,.8
125 142,28,5,1,1,-1,-1,8.05,.95,142,28,5,1,1,-1,-1,8.05,1.
130 143,150,10,-1,1,-1,0,8.1,1.5,143,150,10,-1,1,-1,0,8.1,1.6
135 144,149,18,0,1,-1,0,8.,1.5,144,149,18,0,1,-1,0,8.,1.65
140 145,152,4,1,1,-1,0,8.1,2.3,145,152,4,1,1,-1,0,8.1,2.
145 146,102,6,-1,1,-1,1,7.9,.6,146,102,6,-1,1,-1,1,7.9,.8
150 147,166,13,0,1,-1,1,8.1,2.3,147,166,13,0,1,-1,1,8.1,2.
155 148,111,3,1,1,-1,1,8.,1.,148,111,3,1,1,-1,1,8.,1.1
160 0
165 $DATA'WESTERLY GRANITE'
170 2
175 149,7,5,1,-1,-1,-1,7.9,1.4
180 150,141,2,1,0,-1,-1,7.9,1.2,150,141,2,1,0,-1,-1,7.9,1.
185 151,51,3,1,1,-1,-1,8.,1.,151,51,3,1,1,-1,-1,8.,1.1
190 152,151,3,1,-1,-1,0,8.06,2.9,152,151,3,1,-1,-1,0,8.06,2.7
195 153,161,1,1,0,-1,0,6.1,2.6,153,161,1,1,0,-1,0,6.1,2.4
200 154,162,3,1,1,-1,0,8.06,4.5,154,162,3,1,1,-1,0,8.06,4.6
205 155,92,2,1,-1,-1,1,7.85,2.,155,92,2,1,-1,-1,1,7.85,1.9
210 156,165,5,1,0,-1,1,6.1,3.1,156,165,5,1,0,-1,1,6.1,2.6
215 157,72,2,1,1,-1,1,7.95,3.2,157,72,2,1,1,-1,1,7.95,3.1
220 0
225 $DATA'DRESSER BASALT'
230 4
235 158,34,19,1,-1,-1,-1,6.,6.1,158,34,19,1,-1,-1,-1,6.,3.6
240 159,143,18,1,0,-1,-1,4.,3.,159,143,18,1,0,-1,-1,4.6,2.9
245 160,41,1,1,1,-1,-1,5.,8.
250 161,153,4,1,-1,-1,0,4.7,6.2,161,153,4,1,-1,-1,0,4.1,2.8
255 162,148,9,1,0,-1,0,4.,11.6
260 163,156,20,1,1,-1,0,6.15,4.5,163,156,20,1,1,-1,0,6.15,5.9
265 164,75,6,1,-1,-1,1,4.125,5.
270 165,167,19,1,0,-1,1,6.,10.7,165,167,19,1,0,-1,1,5.9,6.7
275 166,106,10,1,1,-1,1,5.3,4.6,166,106,10,1,1,-1,1,5.7,3.4
280 0
285 $DATA'BEREA SANDSTØNE'
290 6
295 167,53,13,1,-1,-1,-1,8.,7.8,167,53,13,1,-1,-1,-1,8.,7.6
300 168,140,8,1,0,-1,-1,8.,4.5,168,140,8,1,0,-1,-1,8.,4.
305 169,14,17,1,1,-1,-1,8.,5.1,169,14,17,1,1,-1,-1,8.,5.3
310 170,163,7,1,-1,-1,0,8.06,16.6,170,163,7,1,-1,-1,0,8.06,19.
315 171,158,20,1,0,-1,0,7.95,17.1,171,158,20,1,0,-1,0,7.95,17.5
320 172,159,19,1,1,-1,0,7.95,12.1,172,159,19,1,1,-1,0,7.95,10.4
325 173,118,10,1,-1,-1,1,8.,7.2,173,118,10,1,-1,-1,1,8.,6.4
330 174,168,18,1,0,-1,1,8.,20.9,174,168,18,1,0,-1,1,8.,18.9
335 175,80,12,1,1,-1,1,8.05,20.7,175,80,12,1,1,-1,1,8.05,18.1
340 0
345 $DATA'TENNESSEE MARBLE'
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RØCKS3 CØNTINUED

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350 7
355 176,47,20,1,-1,-1,-1,8.,1.3,176,47,20,1,-1,-1,-1,8.,1.3
360 177,142,5,1,0,-1,-1,7.9,.7,177,142,5,1,0,-1,-1,7.9,1.2
365 178,12,1,1,1,-1,-1,8.05,.8,178,12,1,1,1,-1,-1,8.05,.7
370 179,155,12,1,-1,-1,0,7.6,2.3,179,155,12,1,-1,-1,0,8.,2.7
375 180,147,16,1,0,-1,0,8.,2.1,180,147,16,1,0,-1,0,8.,1.7
380 181,146,14,1,1,-1,0,6.25,1.8,181,146,14,1,1,-1,0,8.1,2.
385 182,79,19,1,-1,-1,1,8.1,3.1,182,79,19,1,-1,-1,1,8.1,2.9
390 183,169,1,1,0,-1,1,8.,2.,183,169,1,1,0,-1,1,8.,2.2
395 184,125,8,1,1,-1,1,8.,.9,184,125,8,1,1,-1,1,8.,.9
400 0
405 $DATA'SALEM LIMESTØNE'
410 8
415 185,30,3,1,-1,-1,-1,8.1,16.8,185,30,3,1,-1,-1,-1,8.1,8.5
420 186,145,16,1,0,-1,-1,8.1,4.5,186,145,16,1,0,-1,-1,8.1,3.7
425 187,33,9,1,1,-1,-1,8.1,2.7,187,33,9,1,1,-1,-1,8.1,3.2
430 188,154,7,1,-1,-1,0,8.1,13.,188,154,7,1,-1,-1,0,8.1,11.
435 189,160,13,1,0,-1,0,8.,9.6,189,160,13,1,0,-1,0,8.,9.5
440 190,157,8,1,1,-1,0,8.,5.4,190,157,8,1,1,-1,0,8.,4.7
445 191,95,17,1,-1,-1,1,7.95,1.2,191,95,17,1,-1,-1,1,7.95,2.9
450 192,164,9,1,0,-1,1,8.,11.1,192,164,9,1,0,-1,1,8.,10.6
455 192,164,9,1,0,-1,1,8.,10.,192,164,9,1,0,-1,1,8.,9.8
460 192,164,9,1,0,-1,1,6.,6.9,192,164,9,1,0,-1,1,6.,7.5
465 193,120,5,1,1,-1,1,8.,3.1,193,120,5,1,1,-1,1,8.,3.
470 0
475 -1
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RØCKS4

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100 $DATA'3↑4 FACTØRIAL FRAGMENTATIØN TEST INPUT DATA'
105 $DATA'BARRE GRANITE'
110 3
115 201,11,7,-1,-1,-1,-1,8.15,.8,201,11,7,-1,-1,-1,-1,8.15,.8
120 202,231,8,0,-1,-1,-1,7.9,1.,202,231,8,0,-1,-1,-1,7.9,1.
125 203,13,17,1,-1,-1,-1,8.2,1.3,203,13,17,1,-1,-1,-1,8.2,1.3
130 204,235,4,-1,0,-1,-1,8.,.5,204,235,4,-1,0,-1,-1,8.,.5
135 205,212,7,0,0,-1,-1,8.,.8,205,212,7,0,0,-1,-1,8.,.8
140 206,229,5,1,0,-1,-1,8.,1.,206,229,5,1,0,-1,-1,8.,.9
145 207,22,11,-1,1,-1,-1,8.2,.9,207,22,11,-1,1,-1,-1,8.2,1.
150 208,224,19,0,1,-1,-1,8.1,.85,208,224,19,0,1,-1,-1,7.5,.6
155 209,43,10,1,1,-1,-1,8.2,1.35,209,43,10,1,1,-1,-1,8.2,1.
160 210,233,18,-1,-1,0,-1,8.,.75,210,233,18,-1,-1,0,-1,8.,.8
165 211,216,11,0,-1,0,-1,8.2,.9,211,216,11,0,-1,0,-1,8.2,1.
170 212,236,16,1,-1,0,-1,7.8,1.,212,236,16,1,-1,0,-1,8.,1.1
175 213,221,2,-1,0,0,-1,8.2,.6,213,221,2,-1,0,0,-1,7.5,.4
180 214,223,10,0,0,0,-1,8.2,.8,214,223,10,0,0,0,-1,8.2,.7
185 215,210,12,1,0,0,-1,5.5,.7,215,210,12,1,0,0,-1,5.5,.4
190 216,225,20,-1,1,0,-1,7.9,.6,216,225,20,-1,1,0,-1,7.9,.5
195 217,214,17,0,1,0,-1,8.2,.5,217,214,17,0,1,0,-1,8.2,.75
200 218,209,13,1,1,0,-1,7.9,.7,218,209,13,1,1,0,-1,7.9,.8
205 219,50,19,-1,-1,1,-1,8.2,.8,219,50,19,-1,-1,1,-1,8.2,.9
210 220,232,6,0,-1,1,-1,7.9,.7,220,232,6,0,-1,1,-1,7.9,1.
215 221,31,1,1,-1,1,-1,8.2,1.2,221,31,1,1,-1,1,-1,8.2,1.2
220 222,208,15,-1,0,1,-1,8.,.5,222,208,15,-1,0,1,-1,8.,.8
225 223,217,1,0,0,1,-1,6.8,.5,223,217,1,0,0,1,-1,6.25,.4
230 224,215,3,1,0,1,-1,8.1,.8,224,215,3,1,0,1,-1,8.1,.9
235 225,19,3,-1,1,1,-1,8.15,.3,225,19,3,-1,1,1,-1,8.15,.5
240 226,205,9,0,1,1,-1,7.95,.5,226,205,9,0,1,1,-1,7.95,.5
245 227,37,2,1,1,1,-1,8.1,1.,227,37,2,1,1,1,-1,8.1,.95
250 0
255 3
260 228,290,12,-1,-1,-1,0,5.7,1.8,228,290,12,-1,-1,-1,0,5.7,1.5
265 229,278,16,0,-1,-1,0,6.1,2.0,229,278,16,0,-1,-1,0,6.1,2.1
270 230,250,17,1,-1,-1,0,6.3,2.4,230,250,17,1,-1,-1,0,6.,2.6
275 231,247,12,-1,0,-1,0,6.2,1.4,231,247,12,-1,0,-1,0,6.2,1.
280 232,241,9,0,0,-1,0,6.,2.3,232,241,9,0,0,-1,0,6.,1.8
285 233,273,6,1,0,-1,0,6.1,2.2,233,273,6,1,0,-1,0,6.1,2.3
290 234,245,13,-1,1,-1,0,6.1,1.,234,245,13,-1,1,-1,0,6.1,1.
295 235,279,14,0,1,-1,0,6.,1.4,235,279,14,0,1,-1,0,6.,1.4
300 236,267,20,1,1,-1,0,6.2,1.6,236,267,20,1,1,-1,0,6.2,1.8
305,237,261,2,-1,-1,0,0,6.2,1.3,237,261,2,-1,-1,0,0,6.2,1.35
310 238,266,19,0,-1,0,0,5.4,1.7,238,266,19,0,-1,0,0,5.5,1.8
315 239,239,14,1,-1,0,0,7.9,3.3,239,239,14,1,-1,0,0,7.9,3.
320 240,272,8,-1,0,0,0,6.1,1.2,240,272,8,-1,0,0,0,6.1,1.
325 241,291,7,0,0,0,0,6.3,1.6,241,291,7,0,0,0,0,6.3,1.5
330 242,260,1,1,0,0,0,6.2,1.9,242,260,1,1,0,0,0,5.5,1.5
335 243,252,3,-1,1,0,0,6.3,1.9,243,252,3,-1,1,0,0,6.3,1.9
340 244,277,4,0,1,0,0,6.1,1.3,244,277,4,0,1,0,0,6.1,1.1
345 245,285,15,1,1,0,0,6.1,1.4,245,285,15,1,1,0,0,6.1,1.7
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RØCKS4 CØNTINUED

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350 246,243,15,-1,-1,1,0,6.1,1.1,246,243,15,-1,-1,1,0,6.1,.9
355 247,248,7,0,-1,1,0,6.3,2.1,247,247,7,0,-1,1,0,6.3,2.
360 248,274,18,1,-1,1,0,6.1,2.6,248,274,18,1,-1,1,0,6.1,2.7
365 249,283,9,-1,0,1,0,6.,.8,249,283,9,-1,0,1,0,6.,.9
370 250,286,13,0,0,1,0,6.1,1.4,250,286,13,0,0,1,0,6.1,1.3
375 251,292,17,1,0,1,0,6.3,1.5,251,292,17,1,0,1,0,6.3,1.6
380 252,263,10,-1,1,1,0,6.2,.95,252,263,10,-1,1,1,0,6.2,.8
385 253,268,5,0,1,1,0,6.2,1.1,253,268,5,0,1,1,0,6.2,1.3
390 254,259,11,1,1,1,0,6.2,1.6,254,259,11,1,1,1,0,6.2,1.5
395 0
400 3
405 255,81,6,-1,-1,-1,1,7.95,2.6,255,81,6,-1,-1,-1,1,7.95,2.7
410 256,304,8,0,-1,-1,1,6.1,2.,256,304,8,0,-1,-1,1,6.1,2.1
415 257,76,8,1,-1,-1,1,8.,4.4,257,76,8,1,-1,-1,1,8.,4.4
420 258,315,4,-1,0,-1,1,6.1,1.1,258,315,4,-1,0,-1,1,6.1,1.
425 259,328,7,0,0,-1,1,6.2,1.5,259,328,7,0,0,-1,1,6.2,1.6
430 260,299,10,1,0,-1,1,6.2,2.3,260,299,10,1,0,-1,1,6.2,2.3
435 261,89,16,-1,1,-1,1,7.9,.7,261,89,16,-1,1,-1,1,7.9,.7
440 262,321,9,0,1,-1,1,6.,1.5,262,321,9,0,1,-1,1,6.,1.6
445 263,68,20,1,1,-1,1,7.5,3.,263,68,20,1,1,-1,1,7.5,2.8
450 264,298,2,-1,-1,0,1,6.1,1.5,264,298,2,-1,-1,0,1,6.1,1.5
455 265,316,16,0,-1,0,1,6.1,1.5,265,316,16,0,-1,0,1,6.1,1.3
460 266,302,5,1,-1,0,1,6.2,2.9,266,302,5,1,-1,0,1,6.2,2.8
465 267,313,18,-1,0,0,1,6.1,.9,267,313,18,-1,0,0,1,6.1,1.
470 268,324,12,0,0,0,1,6.2,1.8,268,324,12,0,0,0,1,6.2,1.7
475 269,322,15,1,0,0,1,6.1,2.5,269,322,15,1,0,0,1,6.1,2.1
480 270,319,14,-1,1,0,1,6.,1.3,270,319,14,-1,1,0,1,6.,1.2
485 271,300,19,0,1,0,1,6.2,1.5,271,300,19,0,1,0,1,6.2,1.5
490 272,323,13,1,1,0,1,6.1,1.9,272,323,13,1,1,0,1,6.1,1.6
495 273,82,18,-1,-1,1,1,8.,2.3,273,82,18,-1,-1,1,1,8.,2.
500 274,301,20,0,-1,1,1,6.2,2.3,274,301,20,0,-1,1,1,6.2,2.3
505 275,85,4,1,-1,1,1,8.,1.4,275,85,4,1,-1,1,1,8.,1.4
510 276,295,3,-1,0,1,1,6.2,1.8,276,295,3,-1,0,1,1,6.2,1.5
515 277,296,11,0,0,1,1,6.2,1.7,277,296,11,0,0,1,1,6.2,1.6
520 278,311,6,1,0,1,1,6.1,2.2,278,311,6,1,0,1,1,6.1,2.3
525 279,74,5,-1,1,1,1,8.,1.6,279,74,5,-1,1,1,1,8.,1.8
530 280,297,1,0,1,1,1,6.2,1.4,280,297,1,0,1,1,1,6.2,1.6
535 281,100,14,1,1,1,1,8.,1.,281,100,14,1,1,1,1,8.,1.2
540 0
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RØCKS5

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100 $DATA'3↑4 FACTØRIAL FRAGMENTATIØN TEST INPUT DATA'
105 $DATA'SIØUX QUARTZITE'
110 5
115 282,24,10,-1,-1,-1,-1,9.6,.9,282,24,10,-1,-1,-1,-1,9.6,1.1
120 283,237,15,0,-1,-1,-1,7.3,.7,283,237,15,0,-1,-1,-1,7.3,.7
125 284,36,2,1,-1,-1,-1,10.,1.8,284,36,2,1,-1,-1,-1,10.,1.5
130 285,202,17,-1,0,-1,-1,7.6,.6,285,202,17,-1,0,-1,-1,7.6,.6
135 286,204,9,0,0,-1,-1,8.4,.7,286,204,9,0,0,-1,-1,8.4,.85
140 287,211,21,1,0,-1,-1,7.7,.9,287,211,21,1,0,-1,-1,7.7,.95
145 288,21,20,-1,1,-1,-1,9.5,1.2,288,21,20,-1,1,-1,-1,9.6,1.1
150 289,206,19,0,1,-1,-1,8.2,.5,289,206,19,0,1,-1,-1,8.2,.6
155 290,42,3,1,1,-1,-1,9.25,1.2,290,42,3,1,1,-1,-1,10.2,1.1
160 291,207,15,-1,-1,0,-1,7.7,.6,291,207,15,-1,-1,0,-1,7.7,.7
165 292,203,14,0,-1,0,-1,8.1,.8,292,203,14,0,-1,0,-1,8.2,.75
170 293,226,5,1,-1,0,-1,7.2,.8,293,226,5,1,-1,0,-1,7.1,.7
175 294,218,23,-1,0,0,-1,7.9,.5,294,218,23,-1,0,0,-1,8.1,.5
180 295,234,19,0,0,0,-1,8.2,.8,295,234,19,0,0,0,-1,8.2,.8
185 296,201,5,1,0,0,-1,7.4,.6,296,201,5,1,0,0,-1,7.5,.7
190 297,219,22,-1,1,0,-1,8.1,.4,297,219,22,-1,1,0,-1,8.2,.5
195 298,230,9,0,1,0,-1,8.4,.6,298,230,9,0,1,0,-1,8.4,.6
200 299,238,21,1,1,0,-1,7.6,.7,299,238,21,1,1,0,-1,7.6,.7
205 300,60,8,-1,-1,1,-1,7.9,.7,300,60,8,-1,-1,1,-1,7.9,.8
210 301,220,26,0,-1,1,-1,8.,.8,301,220,26,0,-1,1,-1,8.,.65
215 302,26,18,1,-1,1,-1,9.5,1.1,302,26,18,1,-1,1,-1,9.5,1.25
220 303,227,17,-1,0,1,-1,7.8,.7,303,227,17,-1,0,1,-1,7.8,.7
225 304,222,24,0,0,1,-1,7.85,.4,304,222,24,0,0,1,-1,7.7,.5
230 305,228,14,1,0,1,-1,8.2,.8,305,228,14,1,0,1,-1,8.2,.65
235 306,4,4,-1,1,1,-1,10.,.7,306,4,4,-1,1,1,-1,11.25,.8
240 307,213,25,0,1,1,-1,7.9,.6,307,213,25,0,1,1,-1,7.9,.6
245 308,16,7,1,1,1,-1,11.8,1.,308,16,7,1,1,1,-1,11.8,.8
250 0
255 5
260 309,254,14,-1,-1,-1,0,7.9,1.5,309,254,14,-1,-1,-1,0,8.1,1.7
265 310,257,15,0,-1,-1,0,7.6,1.55,310,257,15,0,-1,-1,0,7.7,1.7
270 311,256,19,1,-1,-1,0,8.7,3.7,311,256,19,1,-1,-1,0,8.7,3.2
275 312,255,9,-1,0,-1,0,8.1,1.2,312,255,9,-1,0,-1,0,8.1,1.
280 313,265,22,0,0,-1,0,8.,1.5,313,265,22,0,0,-1,0,8.,1.7
285 314,275,17,1,0,-1,0,8.4,2.3,314,275,17,1,0,-1,0,8.4,2.2
290 315,258,21,-1,1,-1,0,8.,1.4,315,258,21,-1,1,-1,0,8.,1.2
295 316,281,19,0,1,-1,0,8.2,1.6,316,281,19,0,1,-1,1,8.2,2.1
300 317,249,24,1,1,-1,0,7.85,1.4,317,249,24,1,1,-1,0,5.2,1.
305 318,240,25,-1,-1,0,0,8.2,1.4,318,240,25,-1,-1,0,0,8.2,1.4
310 319,244,22,0,-1,0,0,7.2,2.,319,244,22,0,-1,0,0,7.9,2.7
315 320,276,14,1,-1,0,0,7.65,2.6,320,276,14,1,-1,0,0,7.75,2.5
320 321,288,23,-1,0,0,0,8.2,1.2,321,288,23,-1,0,0,0,8.2,1.1
325 322,251,5,0,0,0,0,7.,1.6,322,251,5,0,0,0,0,7.2,1.55
330 323,264,23,1,0,0,0,8.1,1.7,323,264,23,1,0,0,0,8.,1.6
335 324,269,26,-1,1,0,0,8.3,1.3,324,269,26,-1,1,0,0,8.2,1.4
340 325,271,5,0,1,0,0,7.2,1.35,325,271,5,0,1,0,0,7.,1.4
345 326,287,25,1,1,0,0,8.6,1.8,326,287,25,1,1,0,0,8.6,1.95
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RØCKS5 CØNTINUED

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350 327,262,25,-1,-1,1,0,8.2,1.2,327,262,25,-1,-1,1,0,8.3,1.3
355 328,246,26,0,-1,1,0,8.3,1.9,328,246,26,0,-1,1,0,8.3,1.85
360 329,280,9,1,-1,1,0,8.2,2.3,329,280,9,1,-1,1,0,8.2,2.6
365 330,282,15,-1,0,1,0,7.5,.9,330,282,15,-1,0,1,0,7.5,.85
370 331,253,17,0,0,1,0,8.1,1.3,331,253,17,0,0,1,0,8.1,1.2
375 332,270,24,1,0,1,0,7.7,1.7,332,270,24,1,0,1,0,7.8,1.6
380 333,242,23,-1,1,1,0,8.2,1.,333,242,23,-1,1,1,0,8.3,.9
385 334,284,21,0,1,1,0,7.5,1.2,334,284,21,0,1,1,0,7.3,1.4
390 335,289,22,1,1,1,0,8.,1.6,335,289,22,1,1,1,0,8.,1.65
395 0
400 5
405 336,65,5,-1,-1,-1,1,20.,5.6
410 337,326,17,0,-1,-1,1,7.3,2.3,337,326,17,0,-1,-1,1,6.6,2.
415 338,88,13,1,-1,-1,1,10.,1.5,338,88,13,1,-1,-1,1,10.,1.6
420 339,312,25,-1,0,-1,1,8.7,1.4,339,312,25,-1,0,-1,1,5.,1.
425 340,294,24,0,0,-1,1,7.5,1.4,340,294,24,0,0,-1,1,7.3,1.4
430 341,317,22,1,0,-1,1,8.1,2.5,341,317,22,1,0,-1,1,8.1,2.6
435 342,73,1,-1,1,-1,1,7.7,1.6,342,73,1,-1,1,-1,1,9.7,1.7
440 343,320,24,0,1,-1,1,7.7,1.2,343,320,24,0,1,-1,1,7.5,1.3
445 344,126,12,1,-1,-1,1,9.2,1.3,344,126,12,1,-1,-1,1,9.2,1.
450 345,293,26,-1,-1,0,1,7.9,1.45,345,293,26,-1,-1,0,1,7.6,1.4
455 346,318,26,0,-1,0,1,8.1,2.4
460 346,318,26,0,-1,0,1,8.,2.4
465 347,307,9,1,-1,0,1,8.4,2.8,347,307,9,1,-1,0,1,8.4,2.7
470 348,306,14,-1,0,0,1,8.2,1.4,348,306,14,-1,0,0,1,8.2,1.5
475 349,327,14,0,0,0,1,7.85,1.5,349,327,14,0,0,0,1,7.85,1.35
480 350,310,21,1,0,0,1,7.1,2.,350,310,21,1,0,0,1,7.2,2.1
485 351,305,17,-1,1,0,1,8.1,1.3,351,305,17,-1,1,0,1,8.1,1.2
490 352,308,19,0,1,0,1,6.2,1.5,352,308,19,0,1,0,1,6.3,1.5
495 353,330,19,1,1,0,1,8.2,2.,353,330,19,1,1,0,1,8.2,2.
500 354,83,6,-1,-1,1,1,8.4,1.8,354,83,6,-1,-1,1,1,8.9,2.3
505 355,303,5,0,-1,1,1,6.9,1.8,355,303,5,0,-1,1,1,6.9,1.8
510 356,71,17,1,-1,1,1,18.,6.5
515 357,309,15,-1,0,1,1,7.8,1.,357,309,15,-1,0,1,1,7.6,1.
520 358,314,23,0,0,1,1,8.3,1.3,358,314,23,0,0,1,1,7.,1.
525 359,325,5,1,0,1,1,7.,1.5,359,325,5,1,0,1,1,7.,1.6
530 360,93,11,-1,1,1,1,10.8,.8,360,93,11,-1,1,1,1,10.8,.9
535 361,329,9,0,1,1,1,8.4,1.3,361,329,9,0,1,1,1,8.4,1.4
540 362,98,16,1,1,1,1,10.8,1.,362,98,16,1,1,1,1,10.8,1.
545 0
550 -1
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100 $DATA'ADDITIØNAL FRAGMENTATIØN TEST INPUT DATA'
105 $DATA'CHARCØAL GRANITE'
110 1
115 371,389,12,-1,450,1,-1,8.,.65,371,389,12,-1,450,1,-1,8.,.6
120 372,390,12,1,450,1,-1,7.2,.6,372,390,12,1,450,1,-1,7.4,.4
125 373,378,1,-1,900,1,-1,8.,.85,373,378,1,-1,900,1,-1,8.,.9
130 374,377,1,1,900,1,-1,8.,.8,374,377,1,1,900,1,-1,8.,.5
135 0
140 $DATA'WESTERLY GRANITE'
145 2
150 375,381,2,-1,450,-1,-1,6.1,.45,375,381,2,-1,450,-1,-1,6.1,.4
155 376,382,2,1,450,-1,-1,6.1,.6,376,382,2,1,450,-1,-1,6.1,.4
160 377,379,4,-1,900,-1,-1,8.1,.6,377,379,4,-1,900,-1,-1,8.1,.5
165 378,380,4,1,900,-1,-1,8.1,.55,378,380,4,1,900,-1,-1,8.1,.6
170 0
175 $DATA'DRESSER BASALT'
180 4
185 379,385,1,-1,450,-1,-1,5.7,.5,379,385,1,-1,450,-1,-1,6.,.65
190 380,386,1,1,450,-1,-1,6.2,2.4,380,386,1,1,450,-1,-1,6.2,1.6
195 381,371,5,-1,900,-1,-1,6.,.25,381,371,5,-1,900,-1,-1,6.,.4
200 382,372,5,1,900,-1,-1,6.,.5,382,372,5,1,900,-1,-1,6.,.9
205 0
210 $DATA'BEREA SANDSTØNE'
215 6
220 383,396,9,-1,450,-1,-1,8.,2.,383,396,9,-1,450,-1,-1,8.,1.5
225 384,395,9,1,450,-1,-1,8.,2.55,384,395,9,1,450,-1,-1,8.,3.9
230 385,393,14,-1,900,-1,-1,8.,1.2,385,393,14,-1,900,-1,-1,8.,1.3
235 386,392,14,1,900,-1,-1,8.,2.,386,392,14,1,900,-1,-1,8.,1.8
240 0
245 $DATA'TENNESSEE MARBLE'
250 7
255 387,388,3,-1,450,-1,-1,7.75,.75,387,388,3,-1,450,-1,-1,8.,1.55
260 388,387,3,1,450,-1,-1,8.,.55,388,387,3,1,450,-1,-1,8.,.5
265 389,400,20,-1,900,-1,-1,8.,.75,389,400,20,-1,900,-1,-1,8.,.7
270 390,399,20,1,900,-1,-1,8.,.65,390,399,20,1,900,-1,-1,8.,.5
275 0
280 $DATA'SALEM LIMESTØNE'
285 8
290 391,375,10,-1,450,-1,-1,8.,.7,391,375,10,-1,450,-1,-1,8.,.6
295 392,376,10,1,450,-1,-1,8.,1.15,392,376,10,1,450,-1,-1,8.,.95
300 393,373,11,-1,900,-1,-1,8.,.8,393,373,11,-1,900,-1,-1,8.,.5
305 394,374,11,1,900,-1,-1,8.,.8,394,374,11,1,900,-1,-1,8.,.9
310 434,433,7,5000,900,-1,-1,6.,.08,434,433,7,5000,900,-1,-1,6.,.05
315 435,435,8,10000,900,-1,-1,5.8,.05,435,435,8,10000,900,-1,-1,5.8,.1
320 436,436,16,20000,900,-1,-1,6.,.15,436,436,16,20000,900,-1,-1,6.,.25
325 437,432,16,35000,900,-1,-1,6.,.6,437,432,16,35000,900,-1,-1,6.,.6
330 0
335 -1
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ROCKS7

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100 $DATA'ADDITIONAL FRAGMENTATION TEST INPUT DATA'
105 $DATA'BARRE GRANITE'
110 3
115 395,405,14,-1,300,-1,-1,8.,.6,395,405,14,-1,300,-1,-1,8.,.6
120 396,402,4,1,300,-1,-1,8.,.8,396,402,4,1,300,-1,-1,8.,.8
125 397,406,9,-1,600,-1,-1,8.,.7,397,406,9,-1,600,-1,-1,8.,.65
130 398,384,6,1,600,-1,-1,5.5,.4,398,384,6,1,600,-1,-1,6.1,.45
135 399,403,16,-1,900,-1,-1,8.,.45,399,403,16,-1,900,-1,-1,8.,.65
140 400,397,18,1,900,-1,-1,6.,.45,400,397,18,1,900,-1,-1,6.,.3
145 401,412,14,-1,300,-1,1,8.,1.2,401,412,14,-1,300,-1,1,8.,1.15
150 402,409,18,1,300,-1,1,6.,.65,402,409,18,1,300,-1,1,6.,.65
155 403,411,16,-1,600,-1,1,8.,.8,403,411,16,-1,600,-1,1,8.,1.1
160 404,410,4,1,600,-1,1,8.,1.3,404,410,4,1,600,-1,1,8.,1.1
165 405,417,9,-1,900,-1,1,8.,1.3,405,417,9,-1,900,-1,1,8.,1.4
170 406,407,6,1,900,-1,1,6.,.3,406,407,6,1,900,-1,1,6.,.3
175 431,434,14,10000,900,-1,-1,6.,.01,431,434,14,10000,900,-1,-1,6.,.05
180 432,437,3,20000,900,-1,-1,6.1,.2,432,437,3,20000,900,-1,-1,6.1,.2
185 433,431,16,35000,900,-1,-1,6.,.5,433,431,16,35000,900,-1,-1,6.,.5
190 0
195 $DATA'SIOUX QUARTZITE'
200 5
205 407,404,24,-1,300,1,-1,7.5,.5,407,404,24,-1,300,1,-1,7.5,.3
210 408,383,15,1,300,1,-1,7.8,.55,408,383,15,1,300,1,-1,7.8,.5
215 409,391,21,-1,600,1,-1,8.,.45,409,391,21,-1,600,1,-1,8.,.4
220 410,394,25,1,600,1,-1,8.5,.4,410,394,25,1,600,1,-1,8.5,.65
225 411,401,26,-1,900,1,-1,8.,.3,411,401,26,-1,900,1,-1,8.,.4
230 412,398,22,1,900,1,-1,8.75,.5,412,398,22,1,900,1,-1,8.75,1.1
235 413,418,24,-1,300,1,1,7.5,1.15,413,418,24,-1,300,1,1,7.5,.9
240 414,415,22,1,300,1,1,8.2,1.1,414,415,22,1,300,1,1,8.2,.8
245 415,413,21,-1,600,1,1,8.7,1.,415,413,21,-1,600,1,1,8.8,.8
250 416,414,15,1,600,1,1,7.7,.9,416,414,15,1,600,1,1,7.7,.6
255 417,416,26,-1,900,1,1,8.,1.45,417,416,26,-1,900,1,1,8.,1.2
260 418,408,15,1,900,1,1,7.3,.7,418,408,15,1,900,1,1,7.75,.3
265 0
270 -1
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RØCKS8

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100 $DATA'KERFING FRAGMENTATIØN TEST INPUT DATA'
105 $DATA'CHARCØAL GRANITE'
110 1,50000,900,1.5,.008,.125
115 373,378,1,8.,.85,1,373,378,1,8.,.9,1
120 421,421,5,7.9,1.9,2,421,421,18,7.9,2.,2,421,421,10,7.8,2.,2
125 421,421,5,7.9,2.7,3,421,421,18,7.9,2.6,3,421,421,10,7.8,3.,3
130 0
150 $DATA'WESTERLY GRANITE'
155 2,50000,900,.5,.008,.100
160 377,379,4,8.1,.6,1,377,379,4,8.1,.5,1
165 422,422,2,6.,.8,2,422,422,4,6.,.9,2,422,422,1,6.,1.2,2
170 422,422,2,6.,1.8,3,422,422,4,6.,1.7,3,422,422,1,6.,1.8,3
175 0
200 $DATA'BARRE GRANITE'
205 3,50000,900,.5,.008,.093
210 399,403,16,8.,.45,1,399,403,16,8.,.65,1
215 423,423,16,7.9,1.7,2,423,423,14,7.9,1.3,2,423,423,3,8.,1.3,2
220 423,423,16,7.9,2.6,3,423,423,14,7.9,2.6,3,423,423,3,8.,2.2,3
225 0
250 $DATA'DRESSER BASALT'
255 4,50000,450,.5,.008,.125
260 379,385,1,5.7,.5,1,379,385,1,6.,.65,1
265 424,424,18,6.,1.8,2,424,424,4,6.,1.6,2,424,424,20,5.8,2.7,2
270 424,424,18,6.,3.6,3,424,424,4,6.,2.[illegible],3,424,424,20,5.8,4.,3
275 0
300 $DATA'SIØUX QUARTZITE'
305 5,50000,900,1.5,.008,.125
310 411,401,26,8.,.3,1,411,401,26,8.,.4,1
315 425,425,22,8.3,1.,2,425,425,15,7.7,1.,2,425,425,21,7.1,1.,2
320 425,425,22,8.3,1.5,3,425,425,15,7.7,1.3,3,425,425,21,7.1,1.6,3
325 0
350 $DATA'BEREA SANDSTØNE'
355 6,50000,900,.5,.008,.093
360 385,393,14,8.,1.2,1,385,393,14,8.,1.3,1
365 426,426,2,7.8,3.9,2,426,426,8,7.9,4.4,2,426,426,20,7.9,3.7,2
370 426,426,2,7.8,7.3,3,426,426,8,7.9,7.6,3,426,426,20,7.9,7.0,3
375 0
400 $DATA'TENNESSEE MARBLE'
405 7,50000,900,.5,.008,.125
410 389,400,20,8.,.75,1,389,400,20,8.,.7,1
415 427,427,5,7.8,1.9,2,427,427,14,8.,2.,2,427,427,16,8.,1.9,2
420 427,427,5,7.8,3.,3,427,427,14,8.,2.9,3,427,427,16,8.,2.8,3
425 0
450 $DATA'SALEM LIMESTØNE'
455 8,50000,900,.5,.008,.093
460 393,373,11,8.,.8,1,393,373,11,8.,.5,1
465 428,428,16,8.,3.5,2,428,428,7,7.9,2.4,2,428,428,8,7.9,1.2,2
470 428,428,16,8.,5.6,3,428,428,7,7.9,5.,3,428,428,8,7.9,2.2,3
475 0
500 -1
```

APPENDICES C THROUGH J

TEST RESULTS

*4 FACTORIAL FRAGMENTATION TEST DATA, ROCK TYPE NUMBER: 1

OMB. #	TEST #	SAMPLE #	TREATMENT COMBINATION PRESSURE P	RATE F	STANDOFF S	NOZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JOULES/CU.CM.
1	25	12	50000	50	.5	.0080	734710.25	60784.78
			50000	50	.5	.0080	808181.27	66863.26
2	48	2	80000	50	.5	.0080	1505535.90	124557.50
			80000	50	.5	.0080	1380074.50	114177.71
3	38	19	50000	150	.5	.0080	224494.80	18573.13
			50000	150	.5	.0080	336742.20	27859.69
4	28	5	80000	150	.5	.0080	577497.08	47778.07
			80000	150	.5	.0080	548622.22	45389.16
5	15	13	50000	50	1.5	.0080	734710.25	60784.78
			50000	50	1.5	.0080	577272.34	47759.47
6	46	15	80000	50	1.5	.0080	1083614.10	89650.64
			80000	50	1.5	.0080	1250323.90	103443.05
7	17	1	50000	150	1.5	.0080	267710.05	22148.46
			50000	150	1.5	.0080	297455.61	24609.39
8	32	14	80000	150	1.5	.0080	1363036.60	112768.11
			80000	150	1.5	.0080	1817382.10	150357.47
9	77	20	50000	50	.5	.0136	934257.56	77293.93
			50000	50	.5	.0136	1015497.30	84015.14
10	104	16	80000	50	.5	.0136	3889936.00	321826.08
			80000	50	.5	.0136	4667923.20	386191.29
11	102	6	50000	150	.5	.0136	1281360.20	106010.77
			50000	150	.5	.0136	961020.15	79508.08
12	111	3	80000	150	.5	.0136	1575670.30	130359.93
			80000	150	.5	.0136	1432427.50	118509.03
13	70	7	50000	50	1.5	.0136	1221603.20	101066.90
			50000	50	1.5	.0136	1221603.20	101066.90
14	86	9	80000	50	1.5	.0136	3174975.60	262675.26
			80000	50	1.5	.0136	2976539.70	246258.06
15	87	11	50000	150	1.5	.0136	967102.55	80011.29
			50000	150	1.5	.0136	773682.04	64009.04
16	105	8	80000	150	1.5	.0136	1432427.50	118509.03
			80000	150	1.5	.0136	1575670.30	130359.93

ANALYSIS OF VARIANCE TABLE

OURCE OF ARIATION	SUMS OF SQUARES	OF	F RATIO	TREATMENT EFFECTS
	1.00064 E 13	1	273.26	1.11839 E 6
	4.31037 E 12	1	117.71	-734028.
F	1.74281 E 12	1	47.5936	-466745.
	4.05308 E 10	1	1.10684	-71178.3
S	1.39690 E 10	1	.381473	-41786.6
S	5.65016 E 11	1	15.4298	265758.
FS	1.04131 E 12	1	28.4368	360783.
	7.59949 E 12	1	207.5[illegible]1	974647
N	1.44698 E 12	1	39.515	42[illegible].
N	1.30472 E 12	1	35.63	-403844.
FN	2.58716 E 12	1	70.6518	-568679.
N	4.25534 E 11	1	11.6207	-230633.
SN	5.32457 E 11	1	14.5407	-257987.
SN	6.38599 E 10	1	1.74392	-89344.8
FSN	3.31682 E 10	1	.905778	64389.7
EPLICATE	1.41017 E 10	1	.385098	
RROR	5.49278 E 11	15		
TAL	3.22771 E 13	31		

RROR MEAN SQUARE= 3.66185 E 10

3*2 FACTORIAL FRAGMENTATION TEST DAT

COMB. #	TEST #	SAMPLE #	TREATMENT PRESSURE P	RAT F
140	38	19	50000	15
			50000	15
141	144	17	65000	15
			65000	15
142	28	5	80000	15
			80000	15
143	150	10	50000	15
			50000	15
144	149	18	65000	15
			65000	15
145	152	4	80000	15
			80000	15
146	102	6	50000	15
			50000	15
147	166	13	65000	15
			65000	15
148	111	3	80000	15
			80000	15

ADDITIONAL FRAGMENTATION TEST DATA,

COMB. #	TEST #	SAMPLE #	TREATMENT PRESSURE P	RAT F
371	389	12	50000	45
			50000	45
372	390	12	80000	45
			80000	45
373	378	1	50000	90
			50000	90
374	377	1	80000	90
			80000	90

ANALYSIS OF VARIAN

SOURCE OF VARIATION	SUMS OF SQUARES	OF
P	4.46523 E 10	1
F	4.24360 E 10	1
PF	5.64180 E 9	1
REPLICATE	6.29398 E 9	1
ERROR	7.00101 E 9	3
TOTAL	1.06025 E 11	7

ERROR MEAN SQUARE= 2.333

APPENDIX C

TEST RESULTS - CHARCOAL GRANITE (NO.

ST OATA, RØCK TYPE NUMBER: 1

TMENT COMBINATIØN RATE F	STANØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
150	.5	.0080	224494.80	18573.13
150	.5	.0080	336742.20	27859.69
150	.5	.0080	798605.97	66071.07
150	.5	.0080	499128.73	41294.42
150	.5	.0080	577497.08	47778.07
150	.5	.0080	548622.22	45389.16
150	.5	.0120	409141.77	33849.53
150	.5	.0120	383570.41	31733.93
150	.5	.0120	598954.48	49553.30
150	.5	.0120	544504.07	45048.46
150	.5	.0120	540029.17	44678.23
150	.5	.0120	621033.54	51379.97
150	.5	.0136	1281360.20	106010.77
150	.5	.0136	961020.15	79508.08
150	.5	.0136	508004.55	42028.74
150	.5	.0136	584205.23	48333.05
150	.5	.0136	1575670.30	130359.93
150	.5	.0136	1432427.50	118509.03

OATA, RØCK TYPE NUMBER: 1

TMENT COMBINATIØN RATE F	STANØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
450	1.5	.0080	138150.65	11429.62
450	1.5	.0080	149663.20	12382.09
450	1.5	.0080	272607.32	22553.62
450	1.5	.0080	420269.61	34770.17
900	1.5	.0080	52822.31	4370.15
900	1.5	.0080	49887.73	4127.36
900	1.5	.0080	113586.38	9397.34
900	1.5	.0080	181738.21	15035.75

VARIANCE TABLE

OF	F RATIØ	TREATMENT EFFECTS
1	19.1339	149419.
1	18.1842	-145664.
1	2.41756	-53112.1
1	2.69703	
3		
7		
2.33367 E 9		

KERFING FRAGMENTATIØN TEST OATA, RØCK TYPE NUMBER: 1

PRESSURE = 50000 PSI = 34483.00 NEWTØNS/SQ.CM.
FEEORATE = 900 IPM = 38.10 CM./SEC.
STANOØFF = 1.5 IN. = 3.810 CM.
NØZZLE = .0080 IN. = .20320 MM.

SPACING BETWEEN CUTS = .125 IN. = .317 CM.

CØMB. #	TEST #	SAMPLE #	NUMBER ØF CUTS	SPECIFIC ENERGY FT.LB./CU.IN.	JØULES/CU
373	378	1	1	52822.31	4370.1
		1	1	49857.73	4127.3
421	421	5	2	46671.29	3861.2
		18	2	44337.72	3668.1
		10	2	43776.49	3621.7
421	421	5	3	49264.14	4075.7
		18	3	51158.91	4232.[illegible]
		10	3	43776.49	3621.7

CUT NUMBER	AVERAGE SPECIFIC ENERGY PER CUT FT.LB./CU.IN.	JØULES/CU.CM.
1	51355.02	4248.75
2	39931.51	3303.65
3	55871.10	4622.38
AVERAGE	47901.30	3963.02

ACTORIAL FRAGMENTATION TEST OATA, ROCK TYPE NUMBER: 2

TEST #	SAMPLE #	TREATMENT COMBINATION PRESSURE P	RATE F	STANOOFF S	NOZZL[illegible] N	SPECIFIC ENERGY FT.-LB./CU.IN.	JOULES/CU.CM.
18	2	50000	50	.5	.0080	793027.88	65609.58
		50000	50	.5	.0080	793027.88	65609.58
7	5	80000	50	.5	.0080	1153713.10	95450.15
8	4	50000	150	.5	.0080	454601.97	37610.58
51	3	80000	150	.5	.0080	545214.63	45107.24
		80000	150	.5	.0080	495649.67	41006.58
3	1	50000	50	1.5	.0080	997598.76	82534.34
5	3	80000	50	1.5	.0080	1168317.10	96658.38
		80000	50	1.5	.0080	1168317.1[illegible]	96658.38
23	5	50000	150	1.5	.0080	297455.6[illegible]	24609.39
		50000	150	1.5	.0080	446183.4[illegible]	36914.09
20	1	80000	150	1.5	.0080	511138.72	42288.04
		80000	150	1.5	.0080	629093.81	52046.82
96	4	50000	50	.5	.0136	2956049.30	244562.83
		50000	50	.5	.0136	2149854.00	177863.87
92	2	80000	50	.5	.0136	2319189.70	191873.52
		80000	50	.5	.0136	2441252.30	201972.13
124	1	50000	150	.5	.0136	1557095.90	128823.22
		50000	150	.5	.0136	1557095.90	128823.22
72	2	80000	150	.5	.0136	489319.49	40482.87
		80000	150	.5	.0136	505103.99	41788.77
123	3	50000	50	1.5	.0136	2458572.50	203405.08
		50000	50	1.5	.0136	2919554.90	241543.53
91	4	80000	50	1.5	.0136	3190732.30	263978.86
		80000	50	1.5	.0136	3190732.30	263978.86
113	1	50000	150	1.5	.0136	961020.15	79508.08
		50000	150	1.5	.0136	1537632.20	127212.93
121	5	80000	150	1.5	.0136	1575670.30	130359.93
		80000	150	1.5	.0136	1432427.50	118509.03

ANALYSIS OF VARIANCE TABLE

E OF TION	SUMS OF SQUARES	OF	F RATIO	TREATMENT EFFECTS
	1.27446 E 10	1	.30421	39913.4
	6.40697 E 12	1	200.672	-1.02512 E 6
	2.45483 E 11	1	5.85961	-175172.
	4.19421 E 11	1	10.0115	228971.
	4.66346 E 11	1	11.1315	241440.
	3.12295 E 10	1	.745439	-62479.5
	1.15835 E 11	1	2.76494	120330.
	1.14985 E 13	1	274.465	1.19888 E 6
	2.02170 E 11	1	4.82573	-158969.
	1.81412 E 12	1	43.3025	-476198.
	9.39236 E 10	1	2.24193	-108353.
	2.66304 E 11	1	6.[illegible]5661	182450.
	5.23524 E 11	1	12.[illegible]964	255813.
	2.78782 E 6	1	6.65444 E-5	590.32
	1.26235 E 10	1	.301319	39723.2
CATE	6.13587 E 9	1	.146462	
	6.28412 E 11	15		
	2.47437 E 13	31		

MEAN SQUARE= 4.18941 E 10

3↑2 FACTORIAL FRAGMENTATION TEST OATA, R

COMB. #	TEST #	SAMPLE #	TREATMENT COMB PRESSURE P	RATE F	S
149	7	5	80000	50	
150	141	2	80000	100	
			80000	100	
151	51	3	80000	150	
			80000	150	
152	151	3	80000	50	
			80000	50	
153	161	1	80000	100	
			80000	100	
154	162	3	80000	150	
			80000	150	
155	92	2	80000	50	
			80000	50	
156	165	5	80000	100	
			80000	100	
157	72	2	80000	150	
			80000	150	

ADDITIONAL FRAGMENTATION TEST OATA, ROCK

COMB. #	TEST #	SAMPLE #	TREATMENT COMB PRESSURE P	RATE F	ST
375	381	2	50000	450	
			50000	450	
376	382	2	80000	450	
			80000	450	
377	379	4	50000	900	
			50000	900	
378	380	4	80000	900	
			80000	900	

ANALYSIS OF VARIANCE TA

SOURCE OF VARIATION	SUMS OF SQUARES	OF
P	2.0807[illegible] E 10	1
F	2.13647 E 10	1
PF	1.25317 E 9	1
REPLICATE	2.30223 E 9	1
ERROR	4.75837 E 9	3
TOTAL	5.04863 E 10	7

ERROR MEAN SQUARE= 1.58612 E

APPENDIX D

TEST RESULTS - WESTERLY GRANITE (N

TEST OATA, RØCK TYPE NUMBER: 2

REATMENT CØMBINATIØN URE	RATE F	STANOØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
00	50	.5	.0080	1153713.10	95450.15
00	100	.5	.0080	672999.31	55679.25
00	100	.5	.0080	807599.17	66815.10
00	150	.5	.0080	545214.63	45107.24
00	150	.5	.0080	495649.67	41006.58
00	50	.5	.0120	1278551.80	105778.43
00	50	.5	.0120	1373259.40	113613.87
00	100	.5	.0120	539644.53	44646.41
00	100	.5	.0120	584614.91	48366.95
00	150	.5	.0120	274651.87	22722.77
00	150	.5	.0120	268681.18	22228.80
00	50	.5	.0136	2319189.70	191873.52
00	50	.5	.0136	2441252.30	201972.13
00	100	.5	.0136	581346.10	48096.51
00	100	.5	.0136	693143.42	57345.83
00	150	.5	.0136	489319.49	40482.87
00	150	.5	.0136	505103.99	41788.77

ST OATA, RØCK TYPE NUMBER: 2

REATMENT CØMBINATIØN URE	RATE F	STANOØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
00	450	.5	.0080	152157.59	12588.45
00	450	.5	.0080	171177.28	14162.01
00	450	.5	.0080	230953.98	19107.93
00	450	.5	.0080	346438.46	28661.39
00	900	.5	.0080	75766.99	6268.43
00	900	.5	.0080	90920.39	7522.12
00	900	.5	.0080	167281.76	13839.72
00	900	.5	.0080	153341.62	12686.41

ØF VARIANCE TABLE

	OF	F RATIØ	TREATMENT EFFECTS
0	1	13.1187	102000.
0	1	13.4697	-103355.
	1	.790081	-25031.6
	1	1.45148	
	3		
0	7		
	1.58612 E 9		

KERFING FRAGMENTATIØN TEST OATA, RØCK TYPE NUMBER: 2

PRESSURE = 50000 PSI = 34483.00 NEWTØNS/SO.CM.
FEEDRATE = 900 IPM = 38.10 CM./SEC.
STANOØFF = .5 IN. = 1.270 CM.
NØZZLE = .0080 IN. = .20320 MM.

SPACING BETWEEN CUTS = .100 IN. = .254 CM.

CØMB. #	TEST #	SAMPLE #	NUMBER ØF CUTS	SPECIFIC ENERGY FT.LB./CU.IN.	JØULES
377	379	4	1	75766.99	626
		4	1	90920.39	752
422	422	2	2	84185.55	696
		4	2	74831.60	619
		1	2	56123.70	464
422	422	2	3	56123.70	464
		4	3	59425.09	491
		1	3	56123.70	464

CUT NUMBER	AVERAGE SPECIFIC ENERGY PER CUT FT.LB./CU.IN.	JØULES/CU.CM.
1	83343.69	6895.27
2	62931.88	5206.54
3	40755.28	3371.81
AVERAGE	51843.58	4289.17

FACTORIAL FRAGMENTATION TEST DATA, ROCK TYPE NUMBER: 3

MB. #	TEST #	SAMPLE #	TREATMENT COMBINATION PRESSURE P	RATE F	STANDOFF S	NOZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JOULES/CU.CM.
33	11	7	50000	50	.5	.0080	1029168.30	85146.18
			50000	50	.5	.0080	1029168.30	85146.18
34	13	17	80000	50	.5	.0080	1289642.30	106695.98
			80000	50	.5	.0080	1289642.30	106695.98
35	22	11	50000	150	.5	.0080	306809.56	25383.28
			50000	150	.5	.0080	276128.60	22844.95
36	43	10	80000	150	.5	.0080	413959.26	34248.09
			80000	150	.5	.0080	558845.00	46234.92
37	50	19	50000	50	1.5	.0080	1035482.30	85668.55
			50000	50	1.5	.0080	920428.67	76149.83
38	31	1	80000	50	1.5	.0080	1397112.50	115587.31
			80000	50	1.5	.0080	1397112.50	115587.31
39	19	3	50000	150	1.5	.0080	914816.30	75685.50
			50000	150	1.5	.0080	548889.78	45411.30
40	37	2	80000	150	1.5	.0080	552029.81	45671.08
			80000	150	1.5	.0080	581084.02	48074.82
41	81	6	50000	50	.5	.0136	892710.04	73856.58
			50000	50	.5	.0136	859646.71	71121.15
42	76	8	80000	50	.5	.0136	1074320.70	88881.77
			80000	50	.5	.0136	1074320.70	88881.77
43	69	16	50000	150	.5	.0136	1098308.70	90866.38
			50000	150	.5	.0136	1098308.70	90866.38
44	68	20	80000	150	.5	.0136	492396.97	40737.48
			80000	150	.5	.0136	527568.18	43647.30
45	82	18	50000	50	1.5	.0136	1015497.30	84015.14
			50000	50	1.5	.0136	1167821.90	96617.41
46	85	4	80000	50	1.5	.0136	3376436.40	279342.71
			80000	50	1.5	.0136	3376436.40	279342.71
47	74	5	50000	150	1.5	.0136	486592.48	40257.26
			50000	150	1.5	.0136	432526.65	35784.23
48	100	14	80000	150	1.5	.0136	1575670.30	130359.93
			80000	150	1.5	.0136	1313058.60	108633.28

ANALYSIS OF VARIANCE TABLE

URCE OF IATION	SUMS OF SQUARES	OF	F RATIO	TREATMENT EFFECTS
	1.60981 E 12	1	191.864	448583.
	3.81429 E 12	1	454.601	-690497.
	9.36008 E 11	1	111.557	-342054.
	1.43654 E 12	1	171.212	423753.
	1.49492 E 12	1	178.17	432278.
	3.86182 E 11	1	46.0267	-219711.
	1.33236 E 11	1	15.8796	-129053.
	1.24872 E 12	1	148.827	395083.
	5.88687 E 11	1	70.1619	271267.
	1.04248 E 10	1	1.24247	-36098.5
	2.57925 E 11	1	30.7405	-179557.
	6.25208 E 11	1	74.5147	279555.
	1.86372 E 12	1	222.125	482664.
	9.01995 E 11	1	107.503	-335782.
ON	3.65760 E 6	1	4.35927 E-4	676.166
LICATE	7.81140 E 9	1	.930992	
OR	1.25856 E 11	15		
AL	1.54413 E 13	31		

OR MEAN SQUARE= 8.39040 E 9

ADDITIONAL FRAGMENTATION TEST DATA, R

COMB. #	TEST #	SAMPLE #	TREATMENT C PRESSURE P	RATE F
395	405	14	50000	300
			50000	300
396	402	4	80000	300
			80000	300
397	406	9	50000	600
			50000.	600
398	384	6	80000	600
			80000	600
399	403	16	50000	900
			50000	900
400	397	18	80000	900
			80000	900
401	412	14	50000	300
			50000	300
402	409	18	80000	300
			80000	300
403	411	16	50000	600
			50000	600
404	410	4	80000	600
			80000	600
405	417	9	50000	900
			50000	900
406	407	6	80000	900
			80000	900
431	434	14	10000	900
			10000	900
432	437	3	20000	900
			20000	900
433	431	16	35000	900
			35000	900

ANALYSIS OF VARIANCE, ROCK TYPE NUMBE

MEAN SPECIFIC ENERGY

COMBINATION #	MEAN SPECIFIC ENERGY (I
395	224495.
396	340759.
399	84425.4
400	189311.
401	331447.
402	909041.
405	96249.1
406	656529.

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	OF
P	4.61736 E 11	1
F	1.51799 E 11	1
PF	205813129	1
N	3.33088 E 11	1
PN	2.10096 E 11	1
FN	9.62276 E 9	1
PFN	8.80356 E 6	1
REPLICATE	168992768	1
ERROR	3.29421 E 9	7
TOTAL	1.17002 E 12	15

ERROR MEAN SQUARE= 4.7060

APPENDIX E

TEST RESULTS - BARRE GRANITE (NO

T DATA, RØCK TYPE NUMBER: 3

EATMENT CØMBINATIØN RE	RATE F	STANDØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
0	300	.5	.0080	224494.80	18573.13
0	300	.5	.0080	224494.80	18573.13
0	300	.5	.0080	340759.15	28192.03
0	300	.5	.0080	340759.15	28192.03
0	600	.5	.0080	96212.06	7959.91
0	600	.5	.0080	103612.98	8572.21
0	600	.5	.0080	234271.91	19382.02
0	600	.5	.0080	230958.98	19107.93
0	900	.5	.0080	99775.47	8254.72
0	900	.5	.0080	69075.32	5714.81
0	900	.5	.0080	151448.51	12529.79
0	900	.5	.0080	227172.76	18794.68
0	300	.5	.0136	324394.99	26838.17
0	300	.5	.0136	338499.12	28005.05
0	300	.5	.0136	909040.55	75207.65
0	300	.5	.0136	909040.55	75207.65
0	600	.5	.0136	243296.24	20128.63
0	600	.5	.0136	176942.72	14639.00
0	600	.5	.0136	303013.52	25069.22
0	600	.5	.0136	358106.89	29627.26
0	900	.5	.0136	99813.84	8257.90
0	900	.5	.0136	92684.28	7668.05
0	900	.5	.0136	656529.29	54316.64
0	900	.5	.0136	656529.29	54316.64
0	900	.5	.0080	301191.38	24918.47
0	900	.5	.0080	60238.28	4983.69
0	900	.5	.0080	43304.81	3582.74
0	900	.5	.0080	43304.81	3582.74
0	900	.5	.0080	39443.42	3263.27
0	900	.5	.0080	39443.42	3263.27

YPE NUMBER: 3

FIC ENERGY VALUES

ENERGY [FT.-LB./CU.IN.]

F VARIANCE TABLE

OF	F RATIØ	TREATMENT EFFECTS
1	981.16	339756.
1	322.563	-194807.
1	.43734	-7173.09
1	707.792	288569.
1	446.44	229181.
1	20.4478	-49047.8
1	.018707	-1483.54
1	.359099	
7		
15		
4.70602 E 8		

KERFING FRAGMENTATIØN TEST DATA, RØCK TYPE NUMBER: 3

PRESSURE = 50000 PSI = 34483.00 NEWTØNS/SQ.CM.
FEEDRATE = 900 IPM = 38.10 CM./SEC.
STANDØFF = .5 IN. = 1.270 CM.
NØZZLE = .0080 IN. = .20320 MM.

SPACING BETWEEN CUTS = .093 IN. = .236 CM.

CØMB. #	TEST #	SAMPLE #	NUMBER ØF CUTS	SPECIFIC ENERGY FT.LB./CU.IN.	JØULES/C
399	403	16	1	99775.47	8254.
		16	1	69075.32	5714.
423	423	16	2	52162.03	4315.
		14	2	68211.88	5643.
		3	2	69075.32	5714.
423	423	16	3	51158.91	4232.
		14	3	51158.91	4232.
		3	3	61225.85	5065.

CUT NUMBER	AVERAGE SPECIFIC ENERGY PER CUT FT.LB./CU.IN.	JØULES/CU.CM.
1	84425.39	6984.77
2	50438.88	4172.96
3	42807.46	3541.59
AVERAGE	46623.17	3857.27

3*4 FACTORIAL FRAGMENTATION TEST DATA, ROCK TYPE NUMBER: 3

COMB. #	TEST #	SAMPLE #	TREATMENT COMBINATION PRESSURE P	RATE F	STANDOFF S	NOZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JOULES/CU.CM.
201	11	7	50000	50	.5	.0080	1029168.30	85146.18
			50000	50	.5	.0080	1029168.30	85146.18
202	231	8	65000	50	.5	.0080	1182935.10	97867.77
			65000	50	.5	.0080	1182935.10	97867.77
203	13	17	80000	50	.5	.0080	1289642.30	106695.98
			80000	50	.5	.0080	1289642.30	106695.98
204	235	4	50000	100	.5	.0080	808181.27	66863.26
			50000	100	.5	.0080	808181.27	66863.26
205	212	[illegible]	65000	100	.5	.0080	748693.10	61941.63
			65000	100	.5	.0080	748693.10	61941.63
206	229	5	80000	100	.5	.0080	817821.95	67660.86
			80000	100	.5	.0080	908691.06	75178.74
207	22	11	50000	150	.5	.0080	306809.56	25383.28
			50000	150	.5	.0080	276128.60	22844.95
208	224	19	65000	150	.5	.0080	475640.32	39351.15
			65000	150	.5	.0080	623910.92	51618.02
209	43	10	80000	150	.5	.0080	413959.26	34248.09
			80000	150	.5	.0080	558845.00	46234.92
210	233	18	50000	50	1.0	.0080	1077575.00	89151.02
			50000	50	1.0	.0080	1010226.60	83579.08
211	216	11	65000	50	1.0	.0080	1364285.20	112871.41
			65000	50	1.0	.0080	1227856.70	101584.27
212	236	16	80000	50	1.0	.0080	1594752.80	131938.68
			80000	50	1.0	.0080	1486949.00	123019.75
213	221	2	50000	100	1.0	.0080	690321.51	57112.37
			50000	100	1.0	.0080	947087.43	78355.38
214	223	10	65000	100	1.0	.0080	767410.43	63490.17
			65000	100	1.0	.0080	877040.49	72560.19
215	210	12	80000	100	1.0	.0080	803217.99	66452.63
			80000	100	1.0	.0080	1405631.50	116292.11
216	225	20	50000	150	1.0	.0080	443377.23	36681.93
			50000	150	1.0	.0080	532052.67	44018.31
217	214	17	65000	150	1.0	.0080	818571.12	67722.84
			65000	150	1.0	.0080	545714.08	45148.56
218	209	13	80000	150	1.0	.0080	769142.07	63633.43
			80000	150	1.0	.0080	672999.31	55679.25
219	50	19	50000	50	1.5	.0080	1035482.30	85668.55
			50000	50	1.5	.0080	920428.67	76149.83
220	232	6	65000	50	1.5	.0080	1689907.30	139811.10
			65000	50	1.5	.0080	1182935.10	97867.77
221	31	1	80000	50	1.5	.0080	1397112.50	115587.31
			80000	50	1.5	.0080	1397112.50	115587.31
222	208	15	50000	100	1.5	.0080	808181.27	66863.26
			50000	100	1.5	.0080	505113.30	41789.54
223	217	1	65000	100	1.5	.0080	1018222.60	84240.61
			65000	100	1.5	.0080	1169833.00	96783.79
224	215	3	80000	100	1.5	.0080	1035055.90	85633.28
			80000	100	1.5	.0080	920049.69	76118.47
225	19	3	50000	150	1.5	.0080	914816.30	75685.50
			50000	150	1.5	.0080	548889.78	45411.30
226	205	9	65000	150	1.5	.0080	793614.69	65658.12
			65000	150	1.5	.0080	793614.69	65658.12
227	37	2	80000	150	1.5	.0080	552029.81	45671.08
			80000	150	1.5	.0080	581084.0[illegible]	48074.82
228	290	12	50000	50	.5	.0120	719786.45	59550.09
			50000	50	.5	.0120	863743.74	71460.11
229	278	16	65000	50	.5	.0120	1027581.30	85014.88
			65000	50	.5	.0120	978648.84	80966.55
230	250	17	80000	50	.5	.0120	1207565.20	99905.49
			80000	50	.5	.0120	1061595.80	87829.01
231	247	12	50000	100	.5	.0120	503309.[illegible]2	41640.29
			50000	100	.5	.0120	704633.05	58296.41
232	241	9	65000	100	.5	.0120	439450.30	36357.04
			65000	100	.5	.0120	561519.83	46456.22
233	273	6	80000	100	.5	.0120	637761.72	52763.94
			80000	100	.5	.0120	610032.95	50469.86
234	245	13	50000	150	.5	.0120	462178.67	38237.43
			50000	150	.5	.0120	462178.67	38237.43
235	279	14	65000	150	.5	.0120	481302.71	39819.62
			65000	150	.5	.0120	481302.71	39819.62
236	267	20	80000	150	.5	.0120	594198.76	49159.85
			80000	150	.5	.0120	528176.68	43697.64
237	261	2	50000	50	1.0	.0120	1084050.80	89686.78
			50000	50	1.0	.0120	1043900.80	86365.05
238	266	19	65000	50	1.0	.0120	1070190.70	88540.09
			65000	50	1.0	.0120	1029453.00	85169.74
239	239	14	80000	50	1.0	.0120	1101271.60	91111.50
			80000	50	1.0	.0120	1211398.80	100222.65
240	272	8	50000	100	1.0	.0120	577723.33	47796.78
			50000	100	1.0	.0120	693268.00	57356.14
241	291	7	65000	100	1.0	.0120	663295.29	54876.41
			65000	100	1.0	.0120	707514.98	58534.84

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3↑4 FACTORIAL FRAGMENTATION TEST DATA, ROCK TYPE NUMBER: 3

COMB. #	TEST #	SAMPLE #	PRESSURE P	RATE F	STANDOFF S	NOZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	SPECIFIC ENERGY JOULES/CU.CM.
242	260	1	80000	100	1.0	.0120	750566.86	62096.65
			80000	100	1.0	.0120	843378.89	69775.27
243	252	3	50000	150	1.0	.0120	251227.40	20784.80
			50000	150	1.0	.0120	251227.40	20784.80
244	277	4	65000	150	1.0	.0120	526964.76	43597.38
			65000	150	1.0	.0120	622776.53	51524.17
245	285	15	80000	150	1.0	.0120	668131.33	55276.51
			80000	150	1.0	.0120	550225.80	45521.83
246	243	15	50000	50	1.5	.0120	1260487.30	104283.89
			50000	50	1.5	.0120	1540595.60	127458.09
247	248	7	65000	50	1.5	.0120	1010735.70	83621.20
			65000	50	1.5	.0120	1061272.50	87802.26
248	274	18	80000	50	1.5	.0120	1079289.10	89292.82
			80000	50	1.5	.0120	1039315.40	85985.68
249	283	9	50000	100	1.5	.0120	852378.69	70519.85
			50000	100	1.5	.0120	757669.95	62684.31
250	286	13	65000	100	1.5	.0120	733986.63	60724.92
			65000	100	1.5	.0120	790447.14	65396.06
251	292	17	80000	100	1.5	.0120	966052.18	79924.39
			80000	100	1.5	.0120	905673.92	74929.12
252	263	10	50000	150	1.5	.0120	494479.33	40909.76
			50000	150	1.5	.0120	587194.21	48580.34
253	268	5	65000	150	1.5	.0120	632985.99	52368.83
			65000	150	1.5	.0120	535603.53	44312.09
254	259	11	80000	150	1.5	.0120	594198.76	49159.85
			80000	150	1.5	.0120	633812.01	52437.17
255	81	6	50000	50	.5	.0136	892710.04	73856.58
			50000	50	.5	.0136	859646.71	71121.15
256	304	8	65000	50	.5	.0136	1319871.10	109196.89
			65000	50	.5	.0136	1257020.10	103997.04
257	76	8	80000	50	.5	.0136	1074320.70	88881.77
			80000	50	.5	.0136	1074320.70	88881.77
258	315	4	50000	100	.5	.0136	809512.94	66973.43
			50000	100	.5	.0136	890464.23	73670.78
259	328	7	65000	100	.5	.0136	894338.87	73991.34
			65000	100	.5	.0136	838442.69	69366.88
260	299	10	80000	100	.5	.0136	796398.57	65888.44
			80000	100	.5	.0136	796398.57	65888.44
261	89	16	50000	150	.5	.0136	1098308.70	90866.38
			50000	150	.5	.0136	1098308.70	90866.38
262	321	9	65000	150	.5	.0136	576992.82	47736.35
			65000	150	.5	.0136	540930.77	44752.83
263	68	20	80000	150	.5	.0136	492396.97	40737.48
			80000	150	.5	.0136	527568.18	43647.30
264	298	2	50000	50	1.0	.0136	1187285.60	98227.70
			50000	50	1.0	.0136	1187285.60	98227.70
265	316	16	65000	50	1.0	.0136	1759828.10	145595.86
			65000	50	1.0	.0136	2030570.90	167995.22
266	302	5	80000	50	1.0	.0136	1263252.90	104512.70
			80000	50	1.0	.0136	1308369.10	108245.30
267	313	18	50000	100	1.0	.0136	989404.70	81856.42
			50000	100	1.0	.0136	890464.23	73670.78
268	324	12	65000	100	1.0	.0136	745282.39	61659.45
			65000	100	1.0	.0136	789122.53	65286.47
269	322	15	80000	100	1.0	.0136	720869.16	59639.67
			80000	100	1.0	.0136	858177.57	70999.60
270	319	14	50000	150	1.0	.0136	449162.29	37160.54
			50000	150	1.0	.0136	486592.48	40257.26
271	300	19	65000	150	1.0	.0136	596225.91	49327.56
			65000	150	1.0	.0136	596225.91	49327.56
272	323	13	80000	150	1.0	.0136	632341.37	52315.50
			80000	150	1.0	.0136	750905.37	62124.65
273	82	18	50000	50	1.5	.0136	1015497.30	84015.14
			50000	50	1.5	.0136	1167821.90	96617.41
274	301	20	65000	50	1.5	.0136	1166529.00	96510.44
			65000	50	1.5	.0136	1166529.00	96510.44
275	85	4	80000	50	1.5	.0136	3376436.40	279342.71
			80000	50	1.5	.0136	3376436.40	279342.71
276	295	3	50000	100	1.5	.0136	502812.23	41599.16
			50000	100	1.5	.0136	603374.67	49919.00
277	296	11	65000	100	1.5	.0136	789122.53	65286.47
			65000	100	1.5	.0136	838442.69	69366.88
278	311	6	80000	100	1.5	.0136	819169.50	67772.35
			80000	100	1.5	.0136	783553.44	64825.73
279	74	5	50000	150	1.5	.0136	486592.48	40257.26
			50000	150	1.5	.0136	432526.65	35784.23
280	297	1	65000	150	1.5	.0136	638813.48	52850.96
			65000	150	1.5	.0136	558961.79	46244.59
281	100	14	80000	150	1.5	.0136	1575670.30	130359.93
			80000	150	1.5	.0136	1313058.60	108633.28

ØRIAL FRAGMENTATIØN TEST OATA, RØCK TYPE NUMBER: 4

TEST #	SAMPLE #	TREATMENT COMBINATIØN PRESSURE P	RATE F	STANOØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
54	14	50000	50	.5	.0080	303067.98	25073.72
34	19	80000	50	.5	.0080	201103.76	16637.92
		80000	50	.5	.0080	340759.15	28192.03
29	8	50000	150	.5	.0080	134696.88	11143.88
		50000	150	.5	.0080	252556.65	20894.77
41	1	80000	150	.5	.0080	42594.89	3524.00
57	3	50000	50	1.5	.0080	432954.25	35819.60
58	12	80000	50	1.5	.0080	211505.68	17498.50
9	20	50000	150	1.5	.0080	185208.21	15322.83
		50000	150	1.5	.0080	203729.03	16855.11
35	5	80000	150	1.5	.0080	299381.25	24768.71
94	13	50000	50	.5	.0136	1113080.30	92088.47
		50000	50	.5	.0136	1187285.60	98227.70
75	6	80000	50	.5	.0136	487473.00	40330.10
109	2	50000	150	.5	.0136	386841.02	32004.52
		50000	150	.5	.0136	286548.90	23707.05
106	10	80000	150	.5	.0136	226930.78	18774.66
		80000	150	.5	.0136	330195.61	27318.07
116	15	50000	50	1.5	.0136	1316192.80	108892.58
		50000	50	1.5	.0136	1257654.40	104049.52
90	16	80000	50	1.5	.0136	3840696.30	317752.33
		80000	50	1.5	.0136	4431572.70	366637.30
117	7	50000	150	1.5	.0136	310878.53	25719.91
		50000	150	1.5	.0136	373054.23	30863.90
67	17	80000	150	1.5	.0136	105513.64	8729.46

ANALYSIS ØF VARIANCE TABLE

ØF ØN	SUMS ØF SQUARES	OF	F RATIØ	TREATMENT EFFECTS
	3.16893 E 11	1	26.3894	199027.
	5.25911 E 12	1	437.954	-810795.
	6.46169 E 11	1	53.8099	-284203.
	1.94608 E 12	1	162.06	493213.
	1.44520 E 12	1	120.35	425030.
	1.77285 E 12	1	147.635	-470751.
	1.31625 E 12	1	109.611	-405624.
	4.76621 E 12	1	396.907	771865.
	6.00401 E 11	1	49.9986	273953.
	3.79444 E 12	1	315.983	-688698.
	9.03540 E 11	1	75.2425	-336069.
	1.35263 E 12	1	112.64	411191.
	1.33414 E 12	1	111.101	408372.
	2.14280 E 12	1	178.443	-517543.
	2.13780 E 12	1	178.026	-516938.
TE	2.80681 E 10	1	2.33738	
	1.80125 E 11	15		
	2.99427 E 13	31		

EAN SQUARE= 1.20084 E 10

3↑2 FACTØRIAL FRAGMENTATIØN TEST OATA, RØCK

CØMB. #	TEST #	SAMPLE #	TREATMENT CØMBINA PRESSURE P	RATE F
158	34	19	80000	50
			80000	50
159	143	18	80000	100
			80000	100
160	41	1	80000	150
161	153	4	80000	50
			80000	50
162	148	9	80000	100
163	156	20	80000	150
			80000	150
164	75	6	80000	50
165	167	19	80000	100
			80000	100
166	106	10	80000	150
			80000	150

AOOITIØNAL FRAGMENTATIØN TEST OATA, RØCK TY

CØMB. #	TEST #	SAMPLE #	TREATMENT CØMBINA PRESSURE P	RATE F
379	385	1	50000	450
			50000	450
380	386	1	80000	450
			80000	450
381	371	5	50000	900
			50000	900
382	372	5	80000	900
			80000	900

MEAN SPECIFIC ENERGY VALU

CØMBINATIØN #	MEAN SPECIFIC ENERGY (FT.-LB
379	115788.
380	73357.9
381	109441.
382	106014.

ANALYSIS ØF VARIANCE TABL

SØURCE ØF VARIATIØN	SUMS ØF SQUARES	OF
P	1051427455	1
F	3.46103 E 8	1
PF	760592865	1
REPLICATE	1.40706 E 9	1
ERRØR	2.43052 E 9	3
TØTAL	5.99570 E 9	7

ERRØR MEAN SQUARE= 810171908

DATA, RØCK TYPE NUMBER: 4

ENT CØMBINATIØN RATE F	STANDØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
50	.5	.0080	201103.76	16637.92
50	.5	.0080	340759.15	28192.03
100	.5	.0080	136303.66	11276.81
100	.5	.0080	162154.35	13415.52
150	.5	.0080	42594.89	3524.00
50	.5	.0120	348728.51	28851.36
50	.5	.0120	673607.81	55729.60
100	.5	.0120	79314.63	6561.94
150	.5	.0120	209566.87	17338.10
150	.5	.0120	159839.14	13223.97
50	.5	.0136	487473.00	40330.10
100	.5	.0136	165666.27	13706.07
100	.5	.0136	260161.98	21523.98
150	.5	.0136	226930.78	18774.66
150	.5	.0136	330195.61	27318.07

ATA, RØCK TYPE NUMBER: 4

ENT CØMBINATIØN RATE F	STANDØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
450	.5	.0080	127962.04	10586.68
450	.5	.0080	103612.98	8572.21
450	.5	.0080	58686.30	4855.29
450	.5	.0080	88029.45	7282.94
900	.5	.0080	134696.88	11143.88
900	.5	.0080	84185.55	6964.92
900	.5	.0080	136303.66	11276.81
900	.5	.0080	75724.25	6264.89

ENERGY VALUES

ERGY [FT.-LB./CU.IN.]

ARIANCE TABLE

F	F RATIØ	TREATMENT EFFECTS
	1.29778	-22928.4
	.427196	13154.9
	.938804	19501.2
1	1.73675	
3		
7		
810171908		

APPENDIX F

TEST RESULTS - DRESSER BASALT (NO. 4

KERFING FRAGMENTATIØN TEST DATA, RØCK TYPE NUMBER: 4

PRESSURE = 50000 PSI = 34483.00 NEWTØNS/SQ.CM.
FEEDRATE = 450 IPM = 19.05 CM./SEC.
STANDØFF = .5 IN. = 1.270 CM.
NØZZLE = .0080 IN. = .20320 MM.

SPACING BETWEEN CUTS = .125 IN. = .317 CM.

CØMB. #	TEST #	SAMPLE #	NUMBER ØF CUTS	SPECIFIC ENERGY FT.LB./CU.IN.	JØULES/CU.C
379	385	1	1	127962.04	10586.68
		1	1	103612.98	8572.21
424	424	18	2	74831.60	6191.04
		4	2	84185.55	6964.92
		20	2	48224.81	3989.78
424	424	18	3	56123.70	4643.28
		4	3	69670.80	5764.07
		20	3	48827.62	4039.66

CUT NUMBER	AVERAGE SPECIFIC ENERGY PER CUT FT.LB./CU.IN.	JØULES/CU.CM.
1	115787.51	9579.45
2	49224.33	4072.48
3	44270.91	3662.67
AVERAGE	46747.62	3867.57

FACTORIAL FRAGMENTATION TEST OATA, ROCK TYPE NUMBER: 5

B.	TEST #	SAMPLE #	TREATMENT COMBINATION PRESSURE P	RATE F	STANOOFF S	NOZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JOULES/CU.CM.
5	24	10	50000	50	.5	.0080	1077575.00	89151.02
			50000	50	.5	.0080	881652.30	72941.74
6	36	2	80000	50	.5	.0080	1135863.80	93973.42
			80000	50	.5	.0080	1363036.60	112768.11
7	21	20	50000	150	.5	.0080	266587.57	22055.59
			50000	150	.5	.0080	293884.10	24313.91
8	42	3	80000	150	.5	.0080	525337.02	43462.71
			80000	150	.5	.0080	631953.32	52283.39
9	60	8	50000	50	1.5	.0080	1140112.90	94324.96
			50000	50	1.5	.0080	997598.76	82534.34
0	26	18	80000	50	1.5	.0080	1765751.90	146085.95
			80000	50	1.5	.0080	1553861.70	128555.64
1	4	4	50000	150	1.5	.0080	481060.28	39799.56
			50000	150	1.5	.0080	473543.72	39177.69
2	16	7	80000	150	1.5	.0080	804191.58	66533.18
			80000	150	1.5	.0080	1005239.50	83166.48
3	65	5	50000	50	.5	.0136	1042698.20	86265.55
			50000	50	.5	.0136	1042698.20	86265.55
4	88	13	80000	50	.5	.0136	3939175.70	325899.83
			80000	50	.5	.0136	3692977.20	305531.09
5	73	1	50000	150	.5	.0136	468345.26	38747.61
			50000	150	.5	.0136	555287.89	45940.63
6	126	12	80000	150	.5	.0136	1393862.20	115318.40
			80000	150	.5	.0136	1812020.80	149913.92
7	83	6	50000	50	1.5	.0136	1362458.90	112720.32
			50000	50	1.5	.0136	1129740.80	93463.85
8	71	17	80000	50	1.5	.0136	1636273.00	135373.77
			80000	50	1.5	.0136	1636273.00	135373.77
9	93	11	50000	150	1.5	.0136	1313799.70	108694.59
			50000	150	1.5	.0136	1167821.90	96617.41
0	98	16	80000	150	1.5	.0136	2127154.90	175985.91
			80000	150	1.5	.0136	2127154.90	175985.91

ANALYSIS OF VARIANCE TABLE

RCE OF IATION	SUMS OF SQUARES	OF	F RATIO	TREATMENT EFFECTS
	5.65761 E 12	1	323.009	840953.
	3.09415 E 12	1	176.654	-621908.
	2.18146 E 11	1	12.4546	-165131.
	1.12143 E 10	1	.640255	37440.4
	5.71312 E 11	1	32.6178	-267234.
	1.32288 E 12	1	75.5269	406645.
	4.93181 E 11	1	28.1571	248289.
	4.53794 E 12	1	259.084	753155.
	1.57923 E 12	1	90.1624	444301.
	2.62656 E 10	1	1.49957	57299.2
	1.38108 E 11	1	7.88498	-131391.
	3.81037 E 11	1	21.7545	-218242.
	1.15377 E 12	1	65.8718	-379764.
	1.28486 E 12	1	73.3563	400759.
N	7.02432 E 11	1	40.1038	296317.
LICATE	41687449б	1	2.38005 E-2	
OR	2.62730 E 11	15		
AL	2.14353 E 13	31		

OR MEAN SQUARE= 1.75153 E 10

ADDITIONAL FRAGMENTATION TEST OATA, RO

COMB. #	TEST #	SAMPLE #	TREATMENT CO PRESSURE P	RATE F
407	404	24	50000	300
			50000	300
408	383	15	80000	300
			80000	300
409	391	21	50000	600
			50000	600
410	394	25	80000	600
			80000	600
411	401	26	50000	900
			50000	900
412	398	22	80000	900
			80000	900
413	418	24	50000	300
			50000	300
414	415	22	80000	300
			80000	300
415	413	21	50000	600
			50000	600
416	414	15	80000	600
			80000	600
417	416	26	50000	900
			50000	900
418	408	15	80000	900
			80000	900

ANALYSIS OF VARIANCE, ROCK TYPE NUMBER

MEAN SPECIFIC ENERGY

COMBINATION #	MEAN SPECIFIC ENERGY (F
407	336742.
408	507421.
411	130955.
412	144564.
413	361418.
414	871765.
417	98810.
418	595175.

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	SUMS OF SQUARES	OF
P	3.54620 E 11	1
F	3.06828 E 11	1
PF	7.31462 E 9	1
N	1.63008 E 11	1
PN	1.69095 E 11	1
FN	2.16765 E 8	1
PFN	5.11860 E 9	1
REPLICATE	5.74353 E 10	1
ERROR	1.34294 E 11	7
TOTAL	1.19793 E 12	15

ERROR MEAN SQUARE= 1.91849

TA, ROCK TYPE NUMBER: 5

ENT COMBINATION RATE F	STANDOFF S	NOZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JOULES/CU.CM.
300	1.5	.0080	252556.65	20894.77
300	1.5	.0080	420927.75	34824.62
300	1.5	.0080	483258.42	39981.42
300	1.5	.0080	531584.27	43979.56
600	1.5	.0080	149663.20	12382.09
600	1.5	.0080	168371.10	13929.85
600	1.5	.0080	362056.59	29954.03
600	1.5	.0080	222804.06	18433.25
900	1.5	.0080	149663.20	12382.09
900	1.5	.0080	112247.40	9286.56
900	1.5	.0080	198776.17	16445.35
900	1.5	.0080	90352.80	7475.16
300	1.5	.0136	317342.92	26254.73
300	1.5	.0136	405493.73	33547.71
300	1.5	.0136	734119.11	60735.88
300	1.5	.0136	1009413.80	83511.83
600	1.5	.0136	211667.73	17511.91
600	1.5	.0136	267625.86	22141.49
600	1.5	.0136	421272.96	34853.18
600	1.5	.0136	631909.44	52279.76
900	1.5	.0136	89488.27	7403.63
900	1.5	.0136	108131.66	8946.06
900	1.5	.0136	342333.13	28322.25
900	1.5	.0136	848017.00	70158.99

NUMBER: 5

ENERGY VALUES

RGY [FT.-LB./CU.IN.]

RIANCE TABLE

F RATIO	TREATMENT EFFECTS
18.4843	297750.
15.9932	-276960.
.38127	-42762.8
8.49668	201871.
8.81396	205606.
1.12988 E-2	7361.48
.266804	35772.2
2.99378	

6

.91849 E 10

APPENDIX G

TEST RESULTS - SIOUX QUARTZITE (NO. 5

KERFING FRAGMENTATION TEST DATA, ROCK TYPE NUMBER: 5

PRESSURE = 50000 PSI = 34483.00 NEWTONS/SQ.CM.
FEEDRATE = 900 IPM = 38.10 CM./SEC.
STANDOFF = 1.5 IN. = 3.810 CM.
NOZZLE = .0080 IN. = .20320 MM.

SPACING BETWEEN CUTS = .125 IN. = .317 CM.

COMB. #	TEST #	SAMPLE #	NUMBER OF CUTS	SPECIFIC ENERGY FT.LB./CU.IN.	JOULES/CU.CM.
411	401	26	1	149663.20	12382.09
		26	1	112247.40	9286.56
425	425	22	2	93165.34	7707.85
		15	2	86430.50	7150.65
		21	2	79695.65	6593.46
425	425	22	3	93165.34	7707.85
		15	3	99727.50	8250.76
		21	3	74714.68	6181.37

CUT NUMBER	AVERAGE SPECIFIC ENERGY PER CUT FT.LB./CU.IN.	JOULES/CU.CM.
1	130955.30	10834.32
2	64500.37	5336.31
3	95316.50	7885.82
AVERAGE	79908.44	6611.06

3*4 FACTORIAL FRAGMENTATION TEST DATA, ROCK TYPE NUMBER: 5

COMB. #	TEST #	SAMPLE #	TREATMENT COMBINATION PRESSURE P	RATE F	STANDOFF S	NOZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JOULES/CU.CM.
282	24	10	50000	50	.5	.0080	1077575.00	89151.02
			50000	50	.5	.0080	881652.30	72941.74
283	237	15	65000	50	.5	.0080	1561559.90	129192.53
			65000	50	.5	.0080	1561559.90	129192.53
284	36	2	80000	50	.5	.0080	1135863.80	93973.42
			80000	50	.5	.0080	1363036.60	112768.11
285	202	17	50000	100	.5	.0080	639810.18	52933.42
			50000	100	.5	.0080	639810.18	52933.42
286	204	9	65000	100	.5	.0080	898431.72	74329.95
			65000	100	.5	.0080	739884.94	61212.90
287	211	21	80000	100	.5	.0080	874615.14	72359.53
			80000	100	.5	.0080	828582.77	68551.14
288	21	20	50000	150	.5	.0080	266587.57	22055.59
			50000	150	.5	.0080	293884.10	24313.91
289	206	19	65000	150	.5	.0080	818571.12	67722.84
			65000	150	.5	.0080	682142.60	56435.70
290	42	3	80000	150	.5	.0080	525337.02	43462.71
			80000	150	.5	.0080	631953.32	52283.39
291	207	15	50000	50	1.0	.0080	1296457.50	107259.81
			50000	50	1.0	.0080	1111249.30	91936.98
292	203	14	65000	50	1.0	.0080	1516103.50	125431.79
			65000	50	1.0	.0080	1637142.20	135445.69
293	226	5	80000	50	1.0	.0080	1840099.40	152236.94
			80000	50	1.0	.0080	2073762.80	171568.62
294	218	23	50000	100	1.0	.0080	798079.01	66027.47
			50000	100	1.0	.0080	818283.54	67699.05
295	234	19	65000	100	1.0	.0080	767410.43	63490.17
			65000	100	1.0	.0080	767410.43	63490.17
296	201	5	80000	100	1.0	.0080	1260808.80	104310.50
			80000	100	1.0	.0080	1095297.30	90617.23
297	219	22	50000	150	1.0	.0080	681902.95	56415.88
			50000	150	1.0	.0080	552257.20	45689.90
298	230	9	65000	150	1.0	.0080	698780.22	57812.18
			65000	150	1.0	.0080	698780.22	57812.18
299	238	21	80000	150	1.0	.0080	739934.15	61216.97
			80000	150	1.0	.0080	739934.15	61216.97
300	60	8	50000	50	1.5	.0080	1140112.90	94324.96
			50000	50	1.5	.0080	997598.76	82534.34
301	220	26	65000	50	1.5	.0080	1497386.20	123883.25
			65000	50	1.5	.0080	1842936.90	152471.69
302	26	18	80000	50	1.5	.0080	1765751.90	146085.95
			80000	50	1.5	.0080	1553861.70	128555.64
303	227	17	50000	100	1.5	.0080	562840.53	46565.49
			50000	100	1.5	.0080	562840.53	46565.49
304	222	24	65000	100	1.5	.0080	1469310.20	121560.44
			65000	100	1.5	.0080	1152987.40	95390.10
305	228	14	80000	100	1.5	.0080	1047834.40	86690.48
			80000	100	1.5	.0080	1289642.30	106695.98
306	4	4	50000	150	1.5	.0080	481060.28	39799.56
			50000	150	1.5	.0080	473543.72	39177.69
307	213	25	65000	150	1.5	.0080	657186.16	54370.98
			65000	150	1.5	.0080	657186.16	54370.98
308	16	7	80000	150	1.5	.0080	804191.58	66533.18
			80000	150	1.5	.0080	1005239.50	83166.48
309	254	14	50000	50	.5	.0120	1197118.50	99041.21
			50000	50	.5	.0120	1083022.30	89601.69
310	257	15	65000	50	.5	.0120	1651955.10	136671.20
			65000	50	.5	.0120	1526012.70	126251.61
311	256	19	80000	50	.5	.0120	1081680.00	89490.63
			80000	50	.5	.0120	1250692.50	103473.55
312	255	5	50000	100	.5	.0120	767140.82	63467.86
			50000	100	.5	.0120	920568.98	76161.43
313	265	22	65000	100	.5	.0120	898431.72	74329.95
			65000	100	.5	.0120	792733.87	65585.25
314	275	17	80000	100	.5	.0120	840045.37	69499.47
			80000	100	.5	.0120	878229.25	72658.54
315	258	21	50000	150	.5	.0120	432954.26	35819.60
			50000	150	.5	.0120	505113.30	41789.54
316	281	19	65000	150	.5	.0120	575557.82	47617.63
			65000	150	.5	.0136	563254.89	46599.77
317	249	24	80000	150	.5	.0120	859808.35	71134.52
			80000	150	.5	.0120	797376.40	65969.34
318	240	25	50000	50	1.0	.0120	1331334.30	110145.28
			50000	50	1.0	.0120	1331334.30	110145.28
319	2	22	65000	50	1.0	.0120	1212882.80	100345.43
			65000	50	1.0	.0120	985779.25	81556.47
320	276	14	80000	50	1.0	.0120	1353534.60	111981.98
			80000	50	1.0	.0120	1426077.00	117983.63
321	288	23	50000	100	1.0	.0120	776611.69	64251.42
			50000	100	1.0	.0120	847212.76	70092.45

3*4 FACTO

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3↑4 FACTORIAL FRAGMENTATION TEST DATA, ROCK TYPE NUMBER: 5

COMB. #	TEST #	SAMPLE #	TREATMENT COMBINATION PRESSURE P	RATE F	STANDOFF S	NOZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JOULES/CU.CM.
322	251	5	65000	100	1.0	.0120	736994.77	60973.79
			65000	100	1.0	.0120	782505.05	64738.99
323	264	23	80000	100	1.0	.0120	1095941.50	90670.53
			80000	100	1.0	.0120	1150062.10	95148.09
324	269	26	50000	150	1.0	.0120	483743.12	40021.52
			50000	150	1.0	.0120	443778.11	36715.09
325	271	5	65000	150	1.0	.0120	598954.48	49553.30
			65000	150	1.0	.0120	561519.83	46456.22
326	287	25	80000	150	1.0	.0120	732632.16	60612.86
			80000	150	1.0	.0120	676275.84	55950.33
327	262	25	50000	50	1.5	.0120	1553223.40	128502.83
			50000	50	1.5	.0120	1451229.40	120064.56
328	246	26	65000	50	1.5	.0120	1471773.00	121764.20
			65000	50	1.5	.0120	1511550.70	125055.12
329	280	9	80000	50	1.5	.0120	1640088.60	135689.45
			80000	50	1.5	.0120	1450847.60	120032.97
330	282	15	50000	100	1.5	.0120	947087.43	78355.38
			50000	100	1.5	.0120	1002798.50	82964.52
331	253	17	65000	100	1.5	.0120	1049610.10	86837.39
			65000	100	1.5	.0120	1137077.60	94073.84
332	270	24	80000	100	1.5	.0120	1041821.09	86192.97
			80000	100	1.5	.0120	1121310.60	92769.39
333	242	23	50000	150	1.5	.0120	621289.35	51401.13
			50000	150	1.5	.0120	698740.06	57808.86
334	284	21	65000	150	1.5	.0120	701899.78	58070.27
			65000	150	1.5	.0120	585584.96	48447.20
335	289	22	80000	150	1.5	.0120	766708.03	63432.06
			80000	150	1.5	.0120	743474.50	61509.88
336	65	5	50000	50	.5	.0136	1042698.20	86265.53
337	326	17	65000	50	.5	.0136	1373493.80	113633.26
			65000	50	.5	.0136	1428057.20	118147.46
338	88	13	80000	50	.5	.0136	3939175.70	325899.83
			80000	50	.5	.0136	3692977.20	305531.09
339	312	25	50000	100	.5	.0136	907147.41	75051.03
			50000	100	.5	.0136	729888.72	60385.88
340	294	24	65000	100	.5	.0136	1159137.40	95898.91
			65000	100	.5	.0136	1128227.00	93341.61
341	317	22	80000	100	.5	.0136	957219.70	79193.66
			80000	100	.5	.0136	920403.56	76147.75
342	73	1	50000	150	.5	.0136	468345.26	38747.61
			50000	150	.5	.0136	555287.89	45940.61
343	320	24	65000	150	.5	.0136	925592.64	76577.06
			65000	150	.5	.0136	832201.18	68850.50
344	126	12	80000	50	.5	.0136	4181586.60	345955.20
			80000	50	.5	.0136	5436062.50	449741.76
345	293	26	50000	50	1.0	.0136	1590654.00	131599.58
			50000	50	1.0	.0136	1584901.20	131123.63
346	[illegible]	26	65000	50	1.0	.0136	1460513.10	120832.63
			65000	50	1.0	.0136	1442482.00	119340.87
347	307	9	80000	50	1.0	.0136	1772629.10	146654.92
			80000	50	1.0	.0136	1838282.00	152086.59
348	306	14	50000	100	1.0	.0136	855012.50	70737.75
			50000	100	1.0	.0136	798011.66	66021.90
349	327	14	65000	100	1.0	.0136	1132348.40	93682.58
			65000	100	1.0	.0136	1258164.90	104091.76
350	310	21	80000	100	1.0	.0136	1048805.50	86770.83
			80000	100	1.0	.0136	1012930.90	83802.81
351	305	17	50000	150	1.0	.0136	606369.09	50166.73
			50000	150	1.0	.0136	656899.84	54347.29
352	308	19	65000	150	1.0	.0136	596225.91	49327.56
			65000	150	1.0	.0136	605842.46	50123.16
353	330	19	80000	150	1.0	.0136	807531.03	66809.46
			80000	150	1.0	.0136	807531.03	66809.46
354	83	6	50000	50	1.5	.0136	1362458.90	112720.32
			50000	50	1.5	.0136	1129740.80	93466.85
355	303	5	65000	50	1.5	.0136	1658854.40	137242.00
			65000	50	1.5	.0136	1658854.40	137242.00
356	71	17	80000	50	1.5	.0136	1636273.00	135373.77
357	309	15	50000	100	1.5	.0136	1138626.40	94201.98
			50000	100	1.5	.0136	1109430.80	91786.54
358	314	23	65000	100	1.5	.0136	1381454.00	114291.83
			65000	100	1.5	.0136	1514606.10	125307.91
359	325	5	80000	100	1.5	.0136	1378711.50	114064.94
			80000	100	1.5	.0136	1292542.00	106935.88
360	93	11	50000	150	1.5	.0136	1313799.70	108694.59
			50000	150	1.5	.0136	1167821.90	96617.41
361	329	9	65000	150	1.5	.0136	932065.32	77112.56
			65000	150	1.5	.0136	865489.22	71604.52
362	98	16	80000	150	1.5	.0136	2127154.90	175985.91
			80000	150	1.5	.0136	2127154.90	175985.91

ØRIAL FRAGMENTATIØN TEST DATA, RØCK TYPE NUMBER: 6

TEST #	SAMPLE #	TREATMENT CØMBINATIØN PRESSURE P	RATE F	STANØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
6	9	50000	50	.5	.0080	306953.47	25395.18
		50000	50	.5	.0080	275199.66	22768.09
53	13	80000	50	.5	.0080	209697.94	17348.94
		80000	50	.5	.0080	215216.30	17805.49
55	4	50000	150	.5	.0080	67348.44	5571.94
		50000	150	.5	.0080	67348.44	5571.94
14	17	80000	150	.5	.0080	106904.83	8844.56
		80000	150	.5	.0080	102870.69	8510.80
1	18	50000	50	1.5	.0080	252556.65	20894.77
		50000	50	1.5	.0080	212679.28	17595.60
2	14	80000	50	1.5	.0080	218085.85	18042.90
		80000	50	1.5	.0080	209697.94	17348.94
10	2	50000	150	1.5	.0080	108430.99	8970.82
		50000	150	1.5	.0080	100399.06	8306.32
61	1	80000	150	1.5	.0080	116728.13	9657.27
		80000	150	1.5	.0080	121916.05	10086.48
110	11	50000	50	.5	.0136	729888.72	60385.88
		50000	50	.5	.0136	648789.97	53676.34
118	10	80000	50	.5	.0136	656529.29	54316.64
		80000	50	.5	.0136	738595.45	61106.22
103	5	50000	150	.5	.0136	324394.99	26838.17
		50000	150	.5	.0136	299441.52	24773.70
80	12	80000	150	.5	.0136	76595.08	6336.94
		80000	150	.5	.0136	87597.69	7247.22
107	16	50000	50	1.5	.0136	686954.09	56833.77
		50000	50	1.5	.0136	729888.72	60385.88
97	15	80000	50	1.5	.0136	854084.92	70661.01
		80000	50	1.5	.0136	869901.31	71969.54
99	3	50000	150	1.5	.0136	311419.19	25764.64
		50000	150	1.5	.0136	283108.35	23422.40
84	6	80000	150	1.5	.0136	88026.27	7282.68
		80000	150	1.5	.0136	101004.51	8356.41

ANALYSIS ØF VARIANCE TABLE

F N	SUMS ØF SQUARES	DF	F RATIØ	TREATMENT EFFECTS
	1.24563 E 10	I	18.9077	-39459.3
	9.28607 E 11	1	1409.55	-340699.
	2.47057 E 10	1	37.5012	-55571.6
	3.86120 E 9	1	5.86099	21969.3
	5.49589 E 9	1	8.34231	26210.4
	745434495	1	1.13151	-9652.94
	5.04012 E 9	1	7.6505	-25100.1
	7.18257 E 11	1	1090.26	299637.
	6.37752 E 9	1	9.68056	-28234.5
	3.27019 E 11	1	496.388	-202182.
	6.92812 E 10	1	105.072	-93019.6
	4.36179 E 9	1	6.62085	23350.
	2.28356 E 9	1	3.46627	16895.1
	1.08246 E 10	1	16.4308	-36784.1
	159753947	1	.242494	-4468.7
E	81092608	1	.123092	
	9.88195 E 9	15		
	2.12938 E 12	31		

AN SQUARE= 658796407

3*2 FACTØRIAL FRAGMENTATIØN TEST DATA, RØC

CØMB. #	TEST #	SAMPLE #	TREATMENT CØMBIN PRESSURE P	RATE F	STA
167	53	13	80000	50	
			80000	50	
168	140	8	80000	100	
			80000	100	
169	14	17	80000	150	
			80000	150	
170	163	7	80000	50	
			80000	50	
171	158	20	80000	100	
			80000	100	
172	159	19	80000	150	
			80000	150	
173	118	10	80000	50	
			80000	50	
174	168	18	80000	100	
			80000	100	
175	80	12	80000	150	
			80000	150	

ADDITIØNAL FRAGMENTATIØN TEST DATA, RØCK T

CØMB. #	TEST #	SAMPLE #	TREATMENT CØMBIN PRESSURE P	RATE F	STA
383	396	9	50000	450	
			50000	450	
384	395	9	80000	450	
			80000	450	
385	393	14	50000	900	
			50000	900	
386	392	14	80000	900	
			80000	900	

MEAN SPECIFIC ENERGY VAL

CØMBINATIØN #	MEAN SPECIFIC ENERGY (FT.-L
383	52382.1
384	58934.7
385	35976.7
386	47958.7

ANALYSIS ØF VARIANCE TAE

SØURCE ØF VARIATIØN	SUMS ØF SQUARES	DF
P	1.71765 E 8	1
F	3.74871 E 8	1
PF	1.47390 E 7	1
REPLICATE	7094880	1
ERRØR	426097850	3
TØTAL	994567456	7

ERRØR MEAN SQUARE= 1.42033 E 8

ATA, RØCK TYPE NUMBER: 6

T CØMBINATIØN ATE	STANDØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
50	.5	.0080	209697.94	17348.94
50	.5	.0080	215216.30	17805.49
100	.5	.0080	181738.21	15035.75
100	.5	.0080	204455.49	16915.22
150	.5	.0080	106904.83	8844.56
150	.5	.0080	102870.69	8510.80
50	.5	.0120	223361.46	18479.36
50	.5	.0120	195147.38	16145.13
100	.5	.0120	106935.60	8847.10
100	.5	.0120	104491.36	8644.88
150	.5	.0120	100749.24	8335.29
150	.5	.0120	117217.87	9697.79
50	.5	.0136	656529.29	54315.64
50	.5	.0136	738595.45	61106.22
100	.5	.0136	113086.38	9355.98
100	.5	.0136	125053.20	10346.03
150	.5	.0136	76595.08	6336.94
150	.5	.0136	87597.69	7247.22

. RØCK TYPE NUMBER: 6

T CØMBINATIØN ATE F	STANDØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
450	.5	.0080	44898.96	3714.63
450	.5	.0080	59865.28	4952.83
450	.5	.0080	71269.89	5896.37
450	.5	.0080	46599.54	3855.32
900	.5	.0080	37415.80	3095.52
900	.5	.0080	34537.66	2857.40
900	.5	.0080	45434.55	3758.94
900	.5	.0080	50482.84	4176.60

ERGY VALUES

Y [FT.-LB./CU.IN.]

ANCE TABLE

F RATIØ	TREATMENT EFFECTS
1.20933	9267.28
2.63933	-13690.7
.103772	2714.69

4.99525 E-2

42033 E 8

APPENDIX H

TEST RESULTS - BEREA SANDSTONE (NO. 6)

KERFING FRAGMENTATION TEST DATA, ROCK TYPE NUMBER: 6

PRESSURE = 50000 PSI = 34483.00 NEWTONS/SQ.CM.
FEEDRATE = 900 IPM = 38.10 CM./SEC.
STANDOFF = .5 IN. = 1.270 CM.
NOZZLE = .0080 IN. = .20320 MM.

SPACING BETWEEN CUTS = .093 IN. = .236 CM.

COMB. #	TEST #	SAMPLE #	NUMBER OF CUTS	SPECIFIC ENERGY FT.LB./CU.IN.	JOULES/CU.CM.
385	393	14	1	37415.80	3095.52
		14	1	34537.66	2857.40
426	426	2	2	22449.46	1857.31
		8	2	20153.51	1667.36
		20	2	23966.34	1982.81
426	426	2	3	17990.34	1488.39
		8	3	17501.73	1447.97
		20	3	19001.88	1572.08

CUT NUMBER	AVERAGE SPECIFIC ENERGY PER CUT FT.LB./CU.IN.	JOULES/CU.CM.
1	35976.73	2976.46
2	16042.13	1327.21
3	13329.01	1102.75
AVERAGE	14685.57	1214.96

CTORIAL FRAGMENTATION TEST DATA, ROCK TYPE NUMBER: 7

TEST #	SAMPLE #	TREATMENT COMBINATION PRESSURE P	RATE F	STANDOFF S	NOZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JOULES/CU.CM.
59	6	50000	50	.5	.0080	621677.90	51433.28
		50000	50	.5	.0080	673484.40	55719.38
47	20	80000	50	.5	.0080	1258187.60	104093.64
		80000	50	.5	.0080	1258187.60	104093.64
64	11	50000	150	.5	.0080	316933.83	26220.89
		50000	150	.5	.0080	316933.83	26220.89
12	1	80000	150	.5	.0080	685777.78	56736.45
		80000	150	.5	.0080	783746.03	64841.66
63	4	50000	50	1.5	.0080	425358.57	35191.19
		50000	50	1.5	.0080	621677.90	51433.28
49	7	80000	50	1.5	.0080	2044554.90	169152.16
		80000	50	1.5	.0080	1635643.90	135321.73
39	3	50000	150	1.5	.0080	340951.47	28207.94
		50000	150	1.5	.0080	170475.74	14103.97
62	18	80000	150	1.5	.0080	613366.46	50745.65
		80000	150	1.5	.0080	788614.02	65244.40
108	13	50000	50	.5	.0136	4671287.80	386469.65
		50000	50	.5	.0136	2335643.90	193234.83
79	19	80000	50	.5	.0136	1543902.70	127731.71
		80000	50	.5	.0136	1650378.80	136540.79
66	9	50000	150	.5	.0136	606369.09	50166.73
		50000	150	.5	.0136	437933.23	36231.53
125	8	80000	150	.5	.0136	1750744.80	144844.37
		80000	150	.5	.0136	1750744.80	144844.37
112	10	50000	50	1.5	.0136	1459777.40	120771.77
		50000	50	1.5	.0136	1167821.90	96617.41
119	17	80000	50	1.5	.0136	3889936.00	321826.08
		80000	50	1.5	.0136	4243566.60	351082.99
122	2	50000	150	1.5	.0136	515788.03	42672.69
		50000	150	1.5	.0136	429823.36	35560.58
127	15	80000	150	1.5	.0136	2279094.50	188556.33
		80000	150	1.5	.0136	2279094.50	188556.33

ANALYSIS OF VARIANCE TABLE

E OF TION	SUMS OF SQUARES	DF	F RATIO	TREATMENT EFFECTS
	5.56410 E 12	1	29.7754	833974.
	7.44470 E 12	1	39.8391	-964670.
	1.57968 E 11	1	.845338	140520.
	1.57306 E 11	1	.841796	140226.
	4.45570 E 12	1	23.8439	746299.
	1.56450 E 10	1	8.37216 E-2	-44222.4
	2.83232 E 12	1	15.1567	-595013.
	1.06449 E 13	1	56.9643	1.15352 E 6
	1.48843 E 11	1	.79651	136402.
	1.27631 E 12	1	6.82998	-399424.
	1.32220 E 12	1	7.07555	406541.
	1.96123 E 10	1	.104952	49513.
	2.53526 E 12	1	13.567	562945.
	7.06670 E 10	1	.378163	93986.1
	1.44761 E 12	1	7.74663	-425383.
CATE	1.92191 E 11	1	1.02848	
	2.80304 E 12	15		
	4.10883 E 13	31		

MEAN SQUARE= 1.86869 E 11

3*2 FACTORIAL FRAGMENTATION TEST DATA, R

COMB. #	TEST #	SAMPLE #	TREATMENT COMB PRESSURE P	RATE F	S
176	47	20	80000	50	
			80000	50	
177	142	5	80000	100	
			80000	100	
178	12	1	80000	150	
			80000	150	
179	155	12	80000	50	
			80000	50	
180	147	16	80000	100	
			80000	100	
181	146	14	80000	150	
			80000	150	
182	79	19	80000	50	
			80000	50	
183	169	1	80000	100	
			80000	100	
184	125	8	80000	150	
			80000	150	

ADDITIONAL FRAGMENTATION TEST DATA, ROCK

COMB. #	TEST #	SAMPLE #	TREATMENT COMB PRESSURE P	RATE F	S
387	388	3	50000	450	
			50000	450	
388	387	3	80000	450	
			80000	450	
389	400	20	50000	900	
			50000	900	
390	399	20	80000	900	
			80000	900	

MEAN SPECIFIC ENERGY V

COMBINATION #	MEAN SPECIFIC ENERGY (FT.
387	86961.6
388	346955.
389	62003.3
390	160768.

ANALYSIS OF VARIANCE T

SOURCE OF VARIATION	SUMS OF SQUARES	DF
P	6.43538 E 10	1
F	2.22910 E 10	1
PF	1.29973 E 10	1
REPLICATE	56201984	1
ERROR	3.06352 E 9	3
TOTAL	1.02762 E 11	7

ERROR MEAN SQUARE= 102117230

APPENDIX I

TEST RESULTS - TENNESSEE MARBLE (NO

EST DATA, RØCK TYPE NUMBER: 7

ATMENT CØMBINATIØN E	RATE F	STANDØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
	50	.5	.0080	1258187.60	104093.64
	50	.5	.0080	1258187.60	104093.64
	100	.5	.0080	1153713.10	95450.15
	100	.5	.0080	672999.31	55679.25
	150	.5	.0080	685777.78	56736.45
	150	.5	.0080	783746.03	64841.66
	50	.5	.0120	1520082.10	125760.95
	50	.5	.0120	1363036.60	112768.11
	100	.5	.0120	876237.81	72493.78
	100	.5	.0120	1082411.40	89551.14
	150	.5	.0120	532436.17	44050.04
	150	.5	.0120	621033.54	51379.97
	50	.5	.0136	1543902.70	127731.71
	50	.5	.0136	1650378.80	136540.79
	100	.5	.0136	1181752.70	97769.95
	100	.5	.0136	1074320.70	88881.77
	150	.5	.0136	1750744.80	144844.37
	150	.5	.0136	1750744.80	144844.37

DATA, RØCK TYPE NUMBER: 7

ATMENT CØMBINATIØN E	RATE F	STANDØFF S	NØZZLE N	SPECIFIC ENERGY FT.-LB./CU.IN.	JØULES/CU.CM.
	450	.5	.0080	115988.98	9596.12
	450	.5	.0080	57934.14	4793.07
	450	.5	.0080	330433.[illegible]	27337.72
	450	.5	.0080	363476.[illegible]	30071.49
	900	.5	.0080	59865.28	4952.83
	900	.5	.0080	64141.37	5306.61
	900	.5	.0080	139798.62	11565.96
	900	.5	.0080	181738.21	15035.75

IC ENERGY VALUES

ENERGY (FT.-LB./CU.IN.)

VARIANCE TABLE

OF	F RATIØ	TREATMENT EFFECTS
1	63.0195	179379.
1	21.8289	-105572.
1	12.7278	-80614.1
1	5.50367 E-2	
3		
7		
1021172309		

KERFING FRAGMENTATIØN TEST DATA, RØCK TYPE NUMBER: 7

PRESSURE = 50000 PSI = 34483.00 NEWTØNS/SQ.CM.
FEEDRATE = 900 IPM = 38.10 CM./SEC.
STANDØFF = .5 IN. = 1.270 CM.
NØZZLE = .0080 IN. = .20320 MM.

SPACING BETWEEN CUTS = .125 IN. = .317 CM.

CØMB. #	TEST #	SAMPLE #	NUMBER ØF CUTS	SPECIFIC ENERGY FT.LB./CU.IN.	JØULES/(
389	400	20	1	59865.28	4952
		20	1	64141.37	5306.
427	427	S	2	46080.51	3812
		14	2	44898.96	3714
		16	2	47262.06	3910.
427	427	S	3	43776.49	3621
		14	3	46447.20	3842.
		16	3	48106.03	3979.

CUT NUMBER	AVERAGE SPECIFIC ENERGY PER CUT FT.LB./CU.IN.	JØULES/CU.CM.
1	62003.33	5129.72
2	36664.78	3033.39
3	46168.80	3819.68
AVERAGE	41416.79	3426.54